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Canada

HYDROLOGIC DESIGN METHODOLOGIES
FOR SMALL-SCALE HYDRO AT UNGAUGED SITES
IN BRITISH COLUMBIA

IMP

Integrated Method for Power Analysis

MARCH, 1989

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PREFACE

Feasibility studies for major hydroelectric projects normally involve power production studies based on streamflow data. For many potential projects, and particularly for small-scale hydro, the sites are located far from the nearest stream gauging location and streamflow data are not available. A synthetic record of streamflows can be developed for such cases but in the mountainous terrain of British Columbia this is not a simple task. It usually requires engineering studies with effort and cost beyond the reach of most would-be small-scale developers. The work described in this report addresses this problem.

Many individuals and agencies contributed to the development of the modelling procedures and programs. The power simulation program was first developed by us for the Hydroelectric Engineering Division of the British Columbia Hydro and Power Authority. The watershed model in **IMP** is a close copy of the UBC Watershed Model developed by Anthony Pipes and Michael Quick at the University of British Columbia in the Department of Civil Engineering. This model is a key component of **IMP** and we were fortunate to have the benefit of their years of experience with using it in British Columbia and the assistance of Anthony Pipes in integrating it into the package. The atmospheric data base was developed by Maurice Danard of Atmospheric Dynamics Corporation for the B.C. Ministry of Environment and was made available for use in **IMP** by C. (Hal) Coulson, head of the Surface Water Section. Robin Y. McNeil of the Modelling Section provided helpful suggestions which were incorporated into the file handling routines. The flood frequency program was written by Douglas Ian Smith (now with Proctor and Redfern in Toronto), based on a mathematical procedure developed by Peter S. Eagleson at the Massachusettes Institute of Technology. That program was restructured for **IMP** by Neil Templeton. Paul Flatt (now with Manitoba Hydro) wrote the first version of the hydropower analysis program. The credit for putting the package together belongs to Tung Van Do who personally wrote all of the routines that make it work. Dr. Norman Crawford of HYDROCOMP Inc. was a specialist consultant on this project. His long experience in development of hydrologic models provided an ongoing source of wisdom. Neill Lyons and John Lee of Environment Canada and Roger Bryenton of the Department of Energy, Mines and Resources had a major positive impact on the structure of the reports and the organization of the computer package. Roger devoted many long hours at the computer identifying ambiguities in our documentation and needed revisions to the programs.

This research has brought together an integrated, easy to use, economical package of microcomputer programs and data which should encourage potential small hydro developers to look at their sites in more detail with a view to reducing some of the economic risk. If **IMP** proves successful it will repay its cost many times by supporting wiser investment decisions and reducing the cost of electrical energy development.

Charles D.D. Howard, P. Eng.
Victoria, B.C.
March, 1989

ENVIRONMENT CANADA
Inland Waters Directorate

ENERGY, MINES AND RESOURCES CANADA
Renewable Energy Division

Hydrologic Design Methodologies
for Small-scale Hydro at Ungauged Sites

Phase IIA - British Columbia

INTEGRATED METHOD FOR POWER ANALYSIS (IMP)

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1. SCOPE

Hydrologic Design Methodology for Small-scale Hydro at Ungauged Sites is a national study program undertaken by Energy, Mines and Resources Canada and Environment Canada. Phase I, a methodology for pre-feasibility site evaluation, was developed for use anywhere in Canada, and is described in the report "Hydrologic Design Methodologies for Small-scale Hydro at Ungauged Sites - Phase I." Phase II was titled "Feasibility Level Studies for Atlantic Provinces". The studies for British Columbia, Phase IIA, are described in this report. Section I gives a general overview of the **IMP** package and its development. Section II provides step-by-step instructions for using **IMP.** Section III, Theory and Modeling Procedures, gives the technical details on the four major programs which make up the **IMP** package. Section IV is a report on an April, 1988, peer-review workshop which critically reviewed the entire **IMP** package. Section V is a bibliography.

The purpose of the **IMP** package is to provide a convenient tool for evaluating small-scale hydroelectric power sites. While the package is no substitute for precipitation and streamflow data in the watershed under study, with **IMP** it should be possible for an experienced hydroelectric engineer to evaluate the hydrology and energy potential of an ungauged hydro site in British Columbia with about one day of office studies. The procedures used may have application elsewhere and for other purposes, but the data base and the hydrological assumptions which guide the user are specific to small-scale hydro development in British Columbia.

The package was assembled and the programs and data base were integrated from a number of computer programs developed for other purposes. The scope of the work which led to **IMP** was directed primarily towards integration of the existing programs and information. This approach reduced the volume of programming and hydrological research that would otherwise have been necessary and took advantage of the body of experience already available from previous use of the components of the package. The primary objective of **IMP** is to address the problem posed by hydroelectric development at sites completely lacking in streamflow records. The mountainous terrain of British Columbia with its myriad of micro-climates precluded methods of regional analysis based on regression or comparisons with gauged streams. **IMP** was developed around the philosophy that a conceptual model of physical processes in the atmosphere and on the land is the best way to quantitatively bring together all of the information that can be used to estimate runoff from ungauged watersheds.

In each of six regions (Figure 1.1) of the Province, a streamflow record for one small watershed is provided in the data base. **IMP** can be used to generate synthetic streamflow records for these stations and to compare results obtained by the modelling procedure with the actual data. **IMP** can also be used to explore the significance of modelling parameters and to develop a detailed appreciation for the accuracy which can be obtained under various circumstances.

2. OVERVIEW OF THE IMP PACKAGE

IMP consists of five basic components that are contained in nine independent computer programs. Figure 1.2 illustrates these components and shows how they are tied together by the **IMP** master menu program. The components are:

a. An atmospheric model **(PRECIP)** of annual precipitation and one-in-ten year 24-hour maximum rainfall. This model consists of a data base on a ten minute latitude - longitude grid and a computer program for retrieving information from this data base at specified hydroelectric sites.

b. A watershed model **(BCSIM)** that will generate a continuous daily time series of streamflow for an ungauged site based on daily precipitation and temperature time series and scalar information from the atmospheric model.

c. A flood frequency analysis system **(FFA)** that uses topographic information specific to the site and information from the atmospheric model to generate the flood frequency curve. This is a knowledge-based program which incorporates hydrologic judgment to suggest site-specific parameters.

d. A hydroelectric power simulation program **(POP)** which determines the daily energy output for a run-of-river or reservoir storage site based on selected generation facilities and the hydrologic daily time series generated by the watershed model. An optimization routine performs a sensitivity analysis on the results of a simulation and provides an estimate of the optimal installed capacity from economic data.

e. A graphics analysis package **(GAP)** provides direct visualization of atmospheric and streamflow data, and the results of watershed and power simulation modelling. Frequency and duration analysis of all variables can be presented on annual or seasonal bases.

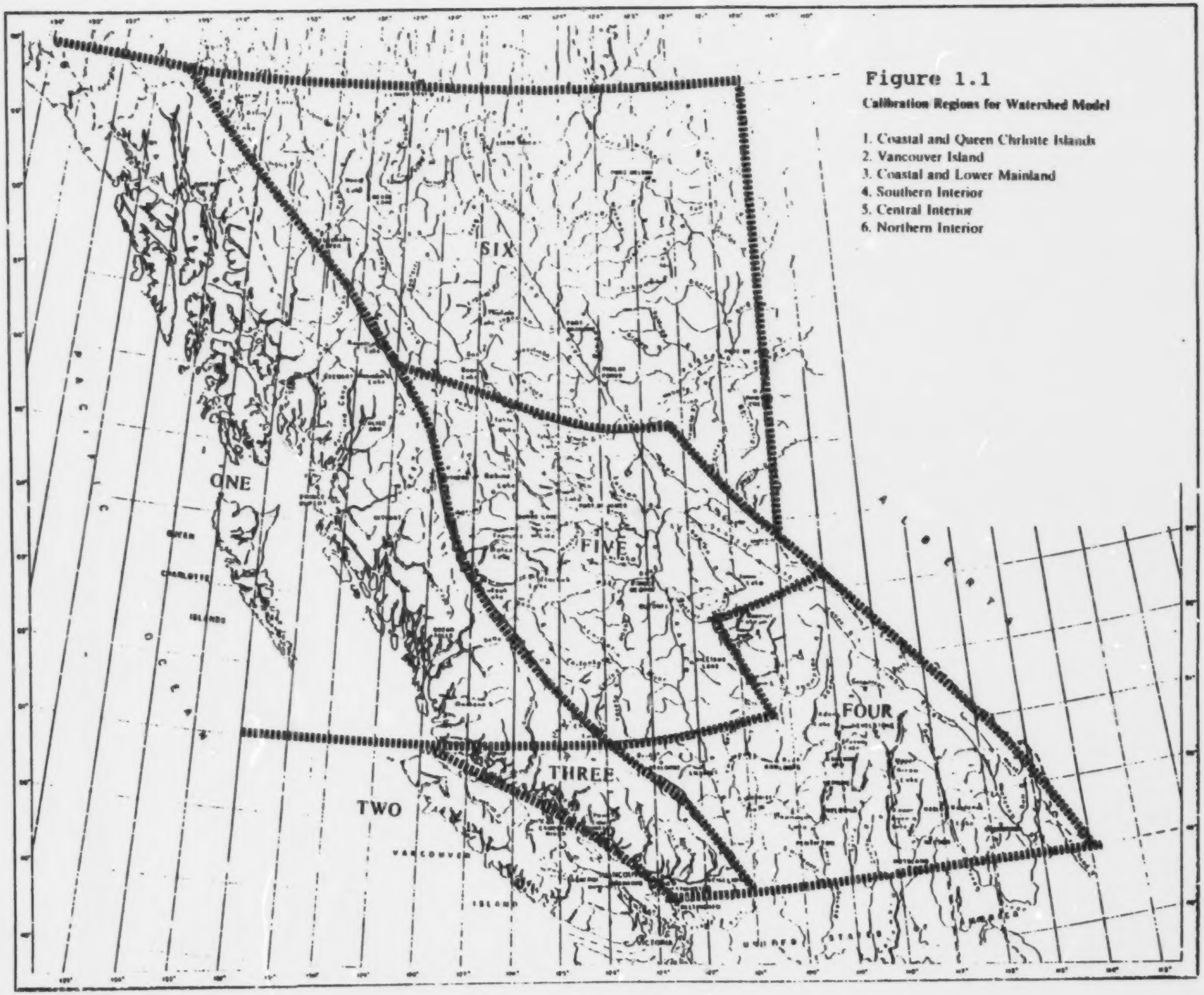
ONE
TWO
THREE
FOUR
FIVE
SIX
PACIFIC OCEAN
QUEEN CHARLOTTE ISLANDS
VANCOUVER ISLAND

Figure 1.1

Calibration Regions for Watershed Model

1. Coastal and Queen Chrlotte Islands
2. Vancouver Island
3. Coastal and Lower Mainland
4. Southern Interior
5. Central Interior
6. Northern Interior

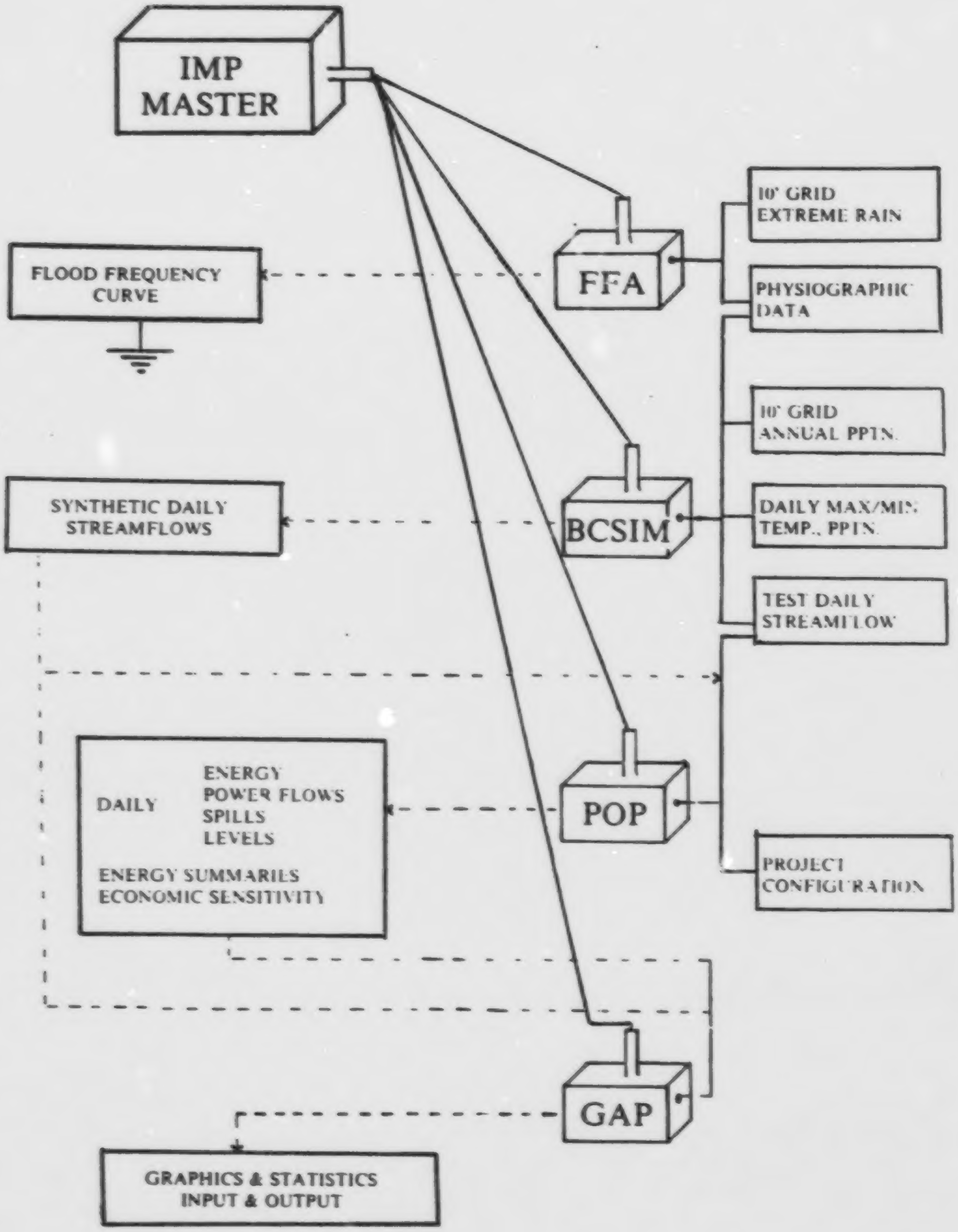
IMP MASTER
FFA
10' GRID EXTREME RAIN
PHYSIOGRAPHIC DATA
FLOOD FREQUENCY CURVE
10' GRID ANNUAL PPTN.
BCSIM
DAILY MAX/MIN TEMP., PPTN.
SYNTHETIC DAILY STREAMFLOWS
TEST DAILY STREAMFLOW
POP
DAILY
ENERGY
POWER FLOWS
SPILLS
LEVELS
ENERGY SUMMARIES
ECONOMIC SENSITIVITY
PROJECT CONFIGURATION
GAP
GRAPHICS & STATISTICS INPUT & OUTPUT

Figure 1.2 IMP PROGRAM FLOW

2.1 Information Needed for a Power Study

A power study based on a simulation approach involves testing selected project configurations to determine their energy output and economic viability. For each project configuration the turbine type, rated head and capacity must be specified along with the penstock properties. In some cases the site characteristics require that points on the tailwater curve be specified. If a reservoir is present it will be necessary to describe its seasonal controlled operating levels and its stage-storage curve. With this information and a sequence of daily inflows to the project, the computer program will determine the daily energy production by considering operating constraints specified for the reservoir, head losses in the penstock, operational limitations and efficiency of the turbine and generator, and reductions in the net head caused by tailwater effects.

2.2 Information Needed for Flood Frequency Analysis

The flood frequency analysis is based on a mathematical manipulation of the statistical properties of rainfall and the runoff routing which it undergoes in flowing to the site. A topographic map must be used to estimate the physical properties of the watershed and stream system. This model uses representative estimates of the stream channel and tributary land surface slopes, average length and width of the main stream, and estimates of the frictional coefficients for the land surface and stream channel. From a topographic map the watershed boundaries must be identified so that the area contributing to the discharge at the site can be estimated. **IMP** will provide an estimate of the average stream width if it is unknown and values of other parameters are suggested by the program.

The flood frequency analysis procedures provided in **IMP** can incorporate both rainfall and snowmelt information into the development of the flood frequency curve. However, for the very small watershed areas commonly encountered at small hydro developments in British Columbia, snowmelt is not an important consideration in the development of extreme floods and this factor is not included in the data base. The rainfall statistics which influence the flood frequency curve were developed from the atmospheric model and a detailed analysis of hourly rainfall events at several key stations in British Columbia. Estimates of the climatological factors necessary to develop a flood frequency curve for an ungauged site are incorporated completely within the IMP package.

2.3 Interpretation and Accuracy of Results

Estimates of energy production incorporate all of the uncertainties in penstock and power plant performance, watershed definition, and atmospheric and runoff modelling. In addition, there are measurement errors in the basic data itself. For example, published streamflow records on small rivers may be in error by 20% or more at very high or very low flows or when icing conditions are encountered.

During the development of the **IMP** package the modelling results were compared with the measured streamflow records and it was found that flow duration curves were within about 10%. On the other hand specific storms sometimes did not show up at all or materialized unexpectedly in synthesized flows. The largest source of inaccuracy is likely to be in the transposition of climatological data from the weather station to the ungauged site. Local experience and additional insight into weather systems in the region of the site could provide supplementary information to assist in interpreting results from the atmospheric model in **IMP**.

2.4 Other Applications

The hydrological features of **IMP** can be used to provide information on water yield, low flows, and floods on ungauged watersheds throughout British Columbia. This information should be useful for studies of water supply, irrigation, bridge and culvert design, and in streamflow forecasting for operational purposes. The power studies component of **IMP** is not limited in application to small hydro projects and it has been used to optimize powerhouse and reservoir configurations at single sites involving more than 1000 MW. The graphic analysis component, **GAP**, provides a capability for reviewing data on temperature, precipitation, streamflow, and results from watershed and reservoir operations modelling. **GAP** operates on standard Water Survey of Canada daily streamflow formats and Atmospheric Environment Service daily precipitation and maximum and minimum temperature formats. It has utility for any application involving the use of these data.

3. ATMOSPHERIC MODEL, (PRECIP)

The Atmospheric model is a precipitation data base prepared for the Province of British Columbia on a latitude and longitude grid of ten minutes. **IMP** contains the grid for both average annual precipitation and one-in-ten year, 24-hour maximum rainfall. The grid covers most of the Province except for some areas in the region of Prince Rupert. The grid data were developed for the B.C. Ministry of Environment by a consulting meteorologist using an atmospheric model which accounted for localized effects of the mountainous terrain and the regional flow of weather systems.

The grid data is accessed by specifying the latitude and longitude to the nearest ten minutes for the ungauged site. **IMP** displays the grid values in the centre of the screen for the specified location along with the surrounding grid point values. An appropriate value for the site can be selected by interpolation using the values displayed on the screen.

The average annual precipitation is required by both the watershed and the flood frequency models. The watershed model uses the average annual precipitation at the site to develop a scalar factor for tranposing the daily record of precipitation and maximum and minimum temperature from the regional weather station to the ungauged watershed. The effects of elevation on temperature and precipitation in the watershed are managed by the watershed modelling procedure itself. The flood frequency model uses the average annual precipitation at the site to estimate rainfall event parameters from internal relationships developed from hydrological research into the characteristics of severe floods and individual rainfall events.

4. ATMOSPHERIC AND STREAMFLOW TIME SERIES DATA

For the purposes of **IMP** the Province has been divided into six modelling regions as shown in Figure 1.1. In each region ten years or more of daily mean discharge for a small gauged stream and precipitation and maximum and minimum temperature for a weather station are included in the data base, Table 1.1. The streamflow data is provided as a convenient reference to the user in evaluating the results of watershed modelling. The daily atmospheric record is used by the watershed model to generate a synthetic daily streamflow sequence for the ungauged sites.

5. IMP - WATERSHED MODEL, (BCSIM)

A characteristic of small hydro developments is the lack of streamflow data at the site. The **IMP** - watershed model (**BCSIM**) remedies this deficiency by generating synthetic daily flow time series based on the topography of the watershed, its location in the regional atmospheric data base, and a continuous daily record of precipitation and temperature data that is representative of the variability in these factors at the site. The development of **IMP** included the hydrological studies that

Table 1.1 DAILY ATMOSPHERIC AND STREAMFLOW DATA BASE

Region	Climate Station				Gauged Streamflow Station			
	Name	Long.	Lat.	Period of Record	Name	Long.	Lat.	Period of Record
1. Queen Charlottes & Coastal 51°N to 60°N	Tasu Sound (15)	132°03'W	52°46'N	1970-1983	Pallant Creek	132°02'W	53°03'N	1967-1983
2. Vancouver Island	Carnation Cr. CDF (61)	125°00'W	48°54'N	1973-1983	Carnation Creek	125°00'W	48°55'N	1973-1983
3. Lower Mainland & Coastal 49°N to 51°N	Gibsons Gower Point (34)	123°32'N	49°23'N	1971-1983	Chapman Creek	123°43'W	49°29'N	1971-1983
4. Southern Interior 49°N to 51°N	McCulloch (1250)	119°12'W	49°48'N	1970-1983	Pearson Creek	119°03'W	49°53'N	1970-1983
5. Central Interior 51°N to 56°N	Barkerville (1265)	121°31'W	53°04'N	1970-1983	McKale River	120°13'W	53°26'N	1971-1983
6. Northern Interior 56°N to 60°N	Atlin (674)	133°42'W	59°34'N	1970-1983	Cottonwood River	129°49'W	59°07'N	1965-1983

were necessary to assemble the data best suited to the generation of synthetic streamflows in British Columbia.

BCSIM was developed from a FORTRAN program based on research at the University of British Columbia in the 1970's and subsequently applied by B.C. Hydro for evaluation of hydroelectric sites in many parts of the Province. The basic modelling procedures have been tested in many research studies as well as in practical applications.

The model consists of a set of procedures which recognize the various paths which water follows from its derivation as rainfall or snowmelt to its arrival at the stream gauge or hydro site. A continuous inventory of soil moisture is maintained based on infiltration factors, evapotranspiration, and the availability of rainfall or snowmelt. In the simulation, precipitation is accummulated as snow when the temperature is low enough. Snowmelt itself is calculated from temperature indices which recognize the various radiation components of the heat budget.

Water is routed to the stream channel network via overland flow and shallow and deep groundwater discharge. The timing of runoff from these three components is controlled by coefficients which were developed for the different regions of British Columbia during development of the **IMP** package.

Drainage area within a watershed is input as a function of elevation and the model accounts for temperature and precipitation variations from parts of the watershed at different elevations. Snow is accummulated or depleted from different elevation bands of the watershed according to the prevailing weather.

The daily hydrographs generated by the model are calculated from the daily meteorological record provided in **IMP** for the hydrological region. Precipitation on the actual watershed may not exactly match what was recorded at the meteorological station and when this is the case, the synthetic streamflows will not match the measured streamflows. Flow duration curves and seasonal statistics of runoff will compare well within a region if the entire period of record provided in the data base is considered. Validation results for individual years showed discrepancies varying from less than 10% in low and average runoff years to up to 40% in high runoff years.

6. FLOOD FREQUENCY MODEL, (FFA)

A flood frequency curve for an ungauged watershed can be developed with little effort from the topographical information available on 1:50,000 scale maps and the rainfall information provided by the atmospheric model. Output from the analysis consists of fifteen points at different return periods on the flood frequency curve and the corresponding time of concentration for the runoff events which would produce these floods. This information describes the magnitude of the peak, its return period, and a general notion of the shape of the flood hydrographs. The mathematical model is based on kimematic wave routing developed by Wooding (1965) and derived probability theory as applied by Eagleson (1971). The model itself was developed by Charles Howard & Associates Ltd. for application to stream crossings by roads and pipelines in Yukon and Northwest Territories. It has been tested on many gauged streams in these northern areas and several small watersheds in British Columbia. Results agree well with measurements if the rainfall and snowmelt regimes over the watersheds are known.

The basic approach of the flood frequency model is to separately identify the routing characteristics of the watershed from the statistics of rainfall events which cause floods. For extreme floods on small watersheds the time required to reach steady flow at the peak discharge is non-linearly related to the rainfall intensity by the kinematic wave equations which route overland and channel flow. The joint probability distribution function of rainfall event duration and average intensity is integrated numerically using this non-linear function to determine the probability of selected flood peaks. Return period is identified from the average annual number of rainfall events and the probability associated with each event. The topographical and climatological parameters have physical meaning and this permits their selection on the basis of site-specific conditions.

The most important factor affecting accuracy is the rainfall probability distribution description. For the watersheds of interest for small hydro developments it is necessary to define these distributions based on an analysis of hourly rainfall data. The flood frequency program automatically estimates these distributions from information provided by the atmospheric model and relationships developed by Charles Howard & Associates Ltd.

The most important topographical factor is the watershed area which contributes directly to the flood peak. For small mountainous coastal streams the entire catchment area is effective during floods. In dryer interior regions of the Province however 20% or less of the catchment area measured from a topographic map contributes to the flood peaks. The appropriate factors to use in different regions of the Province were determined during the development of **IMP**.

7. PROJECT OPERATION PROGRAM, (POP)

The energy which can be generated at the site depends upon the runoff identified by the watershed model and the project configuration, consisting of the selected type of turbine and generator set and matching penstock capacity. If storage is available the operating rules for the reservoir will influence both the average annual energy output and its seasonal distribution. **POP** provides a simulation capability for testing alternative configurations at the site and for estimating the optimal installed capacity.

The program provides a selection of alternative turbine types with the corresponding efficiency curves. Penstock or tunnel friction losses are modelled but it is up to the user to correctly match the penstock diameter to the turbine discharge characteristics. The model quickly computes a daily time series of powerhouse flows, spill, energy production, and reservoir level. A sensitivity analysis automatically determines the effect of increments of turbine capacity on energy production and if cost data and the value of energy is provided the program will estimate the optimal installed capacity.

8. GRAPHICAL ANALYSIS PROGRAM, (GAP)

All of the time series data and results of **IMP** can be viewed graphically on the screen or dumped to a printer using **GAP**. The program also performs frequency analysis on any input data or output results. Histograms and duration curves are tabulated and plotted for any season over the entire period of record or for a particular year. The purpose of GAP is to provide a convenient graphical means for screening data and evaluating results.

9. COMPUTER HARDWARE AND FILES

IMP is a package of computer programs that have been integrated through a common menu and data base. The package was compiled using QUICKBASIC and runs under MS-DOS (Version 3.0 or higher) on an IBM-compatible microcomputer. The required hardware is an IBM-PC/XT or AT (or equivalent) with at least 512K memory, an IBM colour graphics adapter (CGA) or enhanced graphics adapter (EGA) card, and a hard disk drive or two floppy disk drives. We strongly recommend using a system with a large capacity hard disk, for two reasons. First, the program execution will be much faster. Second, the programs are large, and as the analysis proceeds lengthy files are generated. The hard disk thus makes file management much simpler. A math coprocessor, if available, will also significantly reduce processing time.

If you are using an XT with a hard disk or an AT with high-density diskettes, you will have no problem loading and running the entire IMP package at one time. The compiled programs, including the BRUN module, must all be on one disk. Since the total of all the programs is about 375K, you will not be able to run the entire package on an XT without a hard disk. For those of you who have an XT with two floppy disk drives and no hard drive, we have provided a version of IMP which has all of the programs, except the **FFA** module, on one disk, and **FFA** (including the BRUN module) on a separate diskette. This means that if you wish to run **FFA**, it must be run as a stand-alone program, and not under the **IMP** master menu. For further instrtuctions on running the **IMP** package, see Section II.

The accompanying atmospheric, streamflow, and parameter data require an additional three 356K diskettes.

IMP uses a number of programs and data files. Table 1.2 provides a list of these files.

10. LIABILITY

IMP is a tool that can be used to assist an experienced engineer in the evaluation of hydroelectric sites at ungauged watersheds. It is not a substitute for engineering expertise or accurate data. The user is cautioned that the quality of the data may be variable from one part of the Province to the next and the accuracy of results may be correspondingly variable. Results obtained using **IMP** should be reviewed with the same careful scrutiny and detailed checking that is normal in engineering practice. There is no warranty, implied or otherwise, that the programs or the data are accurate.

11. ACKNOWLEDGEMENTS

This package of programs was assembled and integrated with funding provided by the Department of Energy, Mines and Resources and Environment Canada. The British Columbia Ministry of Environment kindly provided the atmospheric data which was essential for practical application of this type of modelling to the mountainous terrain of British

Table 1.2 IMP PROGRAMS AND DATA FILES

1. Computer Programs

Executable	Source
IMP.EXE	IMP.BAS
PRECIP.EXE	PRECIP.BAS
FFA.EXE	FFA.BAS
BCMAN.EXE	BCMAN.BAS
BCSIM.EXE	BCSIM.BAS
POP1.EXE	POPI.BAS
POP2.EXE	POP2.BAS
POP3.EXE	POP3.BAS
GAP.EXE	GAP.BAS
BRUN41.EXE	

2. Weather Data

TASU1.AES
CARN2.AES
GIBS3.AES
MCCUL4.AES
BARK5.AES
ATLIN6.AES
MISSING.AES
DANARD.AVG

3. Streamflow Data

PALL1.WSC
CARN2.WSC
CHAP3.WSC
PEAR4.WSC
MCKAL.WSC
COTT6.WSC

4. Watershed Parameter Data

PALL1.PAR
CARN2.PAR
CHAP3.PAR
PEAR4.PAR
MCKAL5.PAR
COTT6.PAR

5. Example Output Files

CARN2.FFA
CARN2.BCM
CARN.PIN
CARN.POP

Columbia. The individual programs in the package were developed earlier with financial support from Alberta Environment, British Columbia Hydro and Power Authority, British Columbia Disaster Relief Fund, Department of Indian Affairs and Northern Development, Environment Protection Board, Seattle Water Department, Tacoma Department of Public Utilities, the University of British Columbia, and the Washington Department of Ecology.

The watershed model in **IMP** is a close copy of the UBC watershed model developed by Anthony Pipes and Michael Quick in the Department of Civil Engineering at the University of British Columbia, with funding from the British Columbia Disaster Relief Fund and the University.

12. HOW TO OBTAIN IMP

The data and programs are available at a nominal charge for copying from Environment Canada and Energy, Mines and Resources Canada. For information on how to obtain **IMP** contact one of the following:

Head, Energy Project Management
Conservation & Renewable Energy Office
Department of Energy, Mines & Resources
200 - 100 West Pender Street
Vancouver, B.C.
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INTEGRATED METHOD FOR POWER ANALYSIS (IMP)

SECTION II - PRIMER FOR IMP

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Appendix A - Example of Precipitation Estimating Procedure

Appendix B - Example Screens from **IMP**

1. GENERAL

While you are using **IMP**, particularly for the first time, you may feel uncertain about how to proceed when some screens appear. We have tried to anticipate your potential confusion but, depending on your technical background, there may still be some apparent ambiguity. The following sections are intended to help you through some of the questions which may arise. You should be sitting in front of the computer actually running the package as you read through the rest of this Section. Appendix B contains a set of example screens to which the text below is keyed (i.e., B.3 refers you to the third screen of Appendix B).

If you have a large capacity hard disk in your computer, the program disk and data disks should be loaded into one subdirectory. You should then create a CATLOG.DAT file (required by **IMP** on every disk containing data files). The MS-DOS command is, from Drive C:,

```
C:DIR>CATLOG.DAT
```

If you are using floppy disks only, you should place the program diskette in Drive A and the appropriate data diskette (for the modelling region in which your site is located) in Drive B. You have been furnished with floppy disks which are set up to run **IMP** without adding CATLOG.DAT files. You should be aware, however, that many files are created as you run **IMP**, and that you will soon run out of disk space on your floppies if you do not organize your data and parameter files. Remember also that any time you create another data disk, you must also create a CATLOG.DAT file for that disk, or **IMP** will not accept it (whenever a data file is created by **IMP**, however, the CATLOG.DAT file is updated automatically!).

To begin execution simply type in the word **IMP** and this will initiate execution of the package of programs. From then on simply answer the questions as they appear on the screen.

Whenever you have finished reading information displayed on the screen you can touch any key to move on to the next step in the execution.

Please read the warning (B.2) about your responsibility for the results obtained with **IMP**.

2. IMP MASTER MENU

The master menu (B.3) displays eight program options which cover all the capabilities of **IMP**. The first seven options manipulate data files or undertake specific types of analysis. Option 8,

GAP (Graphics Analysis Program), contains a number of graphics routines which can be used to plot the data and output.

After a selection has been made from the master menu, control is transferred to the appropriate program. When that program has finished execution it will automatically transfer you back to the master menu. You can run the individual programs by typing in the exact names shown in the menu. However, at a particular session on the computer it is necessary to run **IMP**, the master menu program, at least once because it creates a file which is used by all of the other sub-programs. If you exit from the master menu by selecting Option 9, the QUIT option, this file will be erased. To avoid confusion, and for the user's convenience, it is probably a good idea to access all of the programs through the master menu.

3. ESTIMATING PRECIPITATION AT YOUR SITE, (PRECIP)

The precipitation data is found in two data files, ANNUALBC and TENBC. The data is stored for calendar years in English units, but the program will convert these to metric units if the metric option is selected (B.5). The watershed model output is in metric units for water years beginning October 1 (i.e., water year 1976 extends from October 1, 1976, to September 30, 1977).

Any drive letter, from A through Z, can be selected for input and output. Do not attach a colon to the drive letter as the program will do this automatically (B.5).

Both the Watershed model that is used to generate synthetic flows for your site and the flood frequency analysis require estimates of precipitation on your basin. The accuracy of your results will be quite sensitive to these estimates and **PRECIP** will help you make them. The precipitation data base is entered by specifying the latitude and longitude of the mid point on the watershed (B.7). It can be located on a topographic map. First enter the longitude to the nearest degree and then to the nearest even ten minutes. The program will prompt you for each of these replies. After these coordinates have been entered you will have to wait about three minutes for the entire precipitation data base to be loaded into a large array. If you have a hard disk the data base will load in less than a minute. Once the array is loaded you can move around from site to site within the Province in a few seconds.

The display shows 81 points in the precipitation grid with the selected latitude and longitude located in the centre, in colour and flashing (B.8). It is a good idea to write down the values on your topographic map at the appropriate ten-minute intervals of latitude and longitude and to use these to sketch the isohyetals over your watershed. This procedure will give you a better appreciation for the variability of the precipitation and the potential for errors in estimates of runoff.

If there are localized points of very high precipitation in the vicinity of your watershed, or if the precipitation is changing rapidly over short distances, there is a high potential for significant errors in the precipitation estimates. In these circumstances the atmospheric model is very sensitive to orographic effects. When the precipitation data base is in error it is usually low. Therefore, if values are selected from the data base they will generally underestimate the runoff potential and estimates of power production will be conservatively low. Table 2.1 provides correction factors which will improve the precipitation estimates for your watershed and Appendix A describes how these factors are used. At many AES station locations there are local points of apparently anomalous high annual precipitation compared to values at the surrounding grid points. These anomalies are obvious in the interior regions. It is probable that the values given by **PRECIP** do not require the regional correction factors of Table 2.1 at such locations (see also Section III, Theory and Modelling Procedures).

Table 2.1: PRECIPITATION ADJUSTMENT FACTORS

Region	Description	Adjustment
1	Queen Charlotte Islands	2.00
1	Mainland Coast	1.75
1	Inland Mainland 100 km. or more from Coast	1.35
2	Vancouver Island	1.15
3	Lower Mainland and Southern Coast	1.15
4	Southern Interior	1.15
5	Central Interior	2.00
6	Northern Interior	2.00

NOTE: Average annual and 24-hour maximum precipitation given by **PRECIP** should be multiplied by the values in this table.

The same considerations are of concern with regard to the ten-year return period, 24-hour maximum rainfall (B.9). This information is used in the flood frequency analysis (**FFA**).

The estimated annual precipitation is the most important single variable used in estimating runoff for power analysis and for evaluating the flood frequency curve. **PRECIP** will help you to estimate this value but if other sources of information are available they should be consulted as well.*

4. FLOOD FREQUENCY ANALYSIS, (FFA)

Simulation of average daily discharge as described in the previous section is not suitable for evaluating flood peaks which might endanger the safety of a small hydro plant. These less frequent events produce very high flood peaks in a few hours on the watersheds of interest for small hydro developments. To provide estimates of such floods **FFA** uses a completely different technique involving additional data to describe how the watershed and stream channel route heavy rainfall to the site. The statistics of these heavy rainfall events were developed for **IMP** from an analysis of hourly rainfall data and empirical relationships with the grid point estimates provided by **PRECIP**.

To use **FFA** it will be necessary to measure certain parameters from a topographic map (Figure 2.1). The watershed above the penstock intake should be delineated on the map and its area should be measured (by planimetering or by counting squares). The topographic map should also be used to estimate representative values for the slope of the stream and the catchment. These parameters need not be calculated with great precision since they have only a secondary effect on the flood frequency curve. Reasonable estimates are easily obtained by inspection of the topographic map.

FFA offers eight options in its menu of functions (B.11). To perform a flood frequency analysis it is necessary to execute these functions in a reasonable sequence. For example, it is illogical to attempt to revise the data before it has actually been entered or read from an old file.

---

*Note: It is important to point out here that the method used by Danard to construct the 10-minute latitude-longitude grid results in precipitation values at the grid points which are not necessarily (in fact, probably will not be) the precipitation values at ground elevation, but rather at some unknown elevation related to the elevation of the nearest AES station. The user is therefore cautioned to exercise care in applying grid values. For more detail, see the discussion in Section IV.

The data base includes a number of files, one for a watershed in each of six regions in the Province, which were analyzed during the development of **IMP**. For convenience you can retrieve one of these files and edit it, or directly input the data for your watershed.

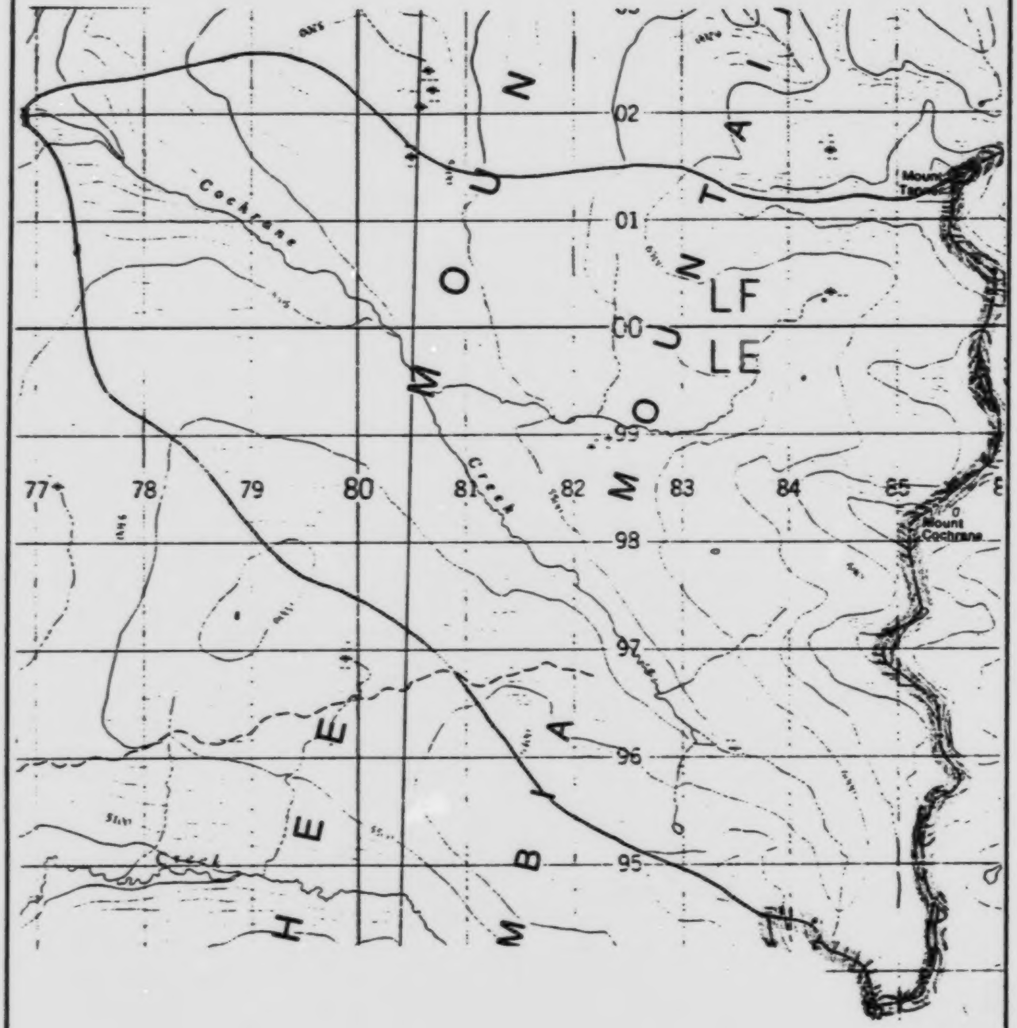
The name of the catchment (B.12) should be kept as short as possible since this appears on all of the output from the program. Average annual precipitation and the ten-year 24-hour rainfall can be estimated from **PRECIP** or from any other information which might be available. These values are used by **FFA** to estimate various parameters from built-in routines.

The length and slope of the stream and the slope of the catchment can be estimated from the topographic map. The stream slope can be estimated by simply dividing the difference between high and low elevations of the watershed by the length of the stream. The watershed slope can be estimated similarly using distance and drop across the predominant area of the watershed towards the stream. The stream width for an ungauged watershed is often unknown since the site may not yet have been visited. The program uses an internal routine based on morphological relationships for British Columbia to provide a first guess at the stream width. If this estimate appears reasonable it can be accepted by touching the return key, if a better estimate is available it can be input directly before touching return.

Manning's n for the stream and the catchment have a secondary influence on the flood frequency curve. Notice that the value suggested by the program for the catchment is about ten times greater than the value normally used for the stream.

The next parameter in **FFA** is the product of Phil and Phi2. Phil represents, approximately, the ratio between long term runoff and long term precipitation. Values in British Columbia range from 0.8 in the humid regions of the coast to 0.2 in the hot interior valleys, but the flood frequency curve is not extremely sensitive to the value chosen.

Phi2 is the ratio of the direct runoff which takes place during a flood event to the long term average runoff, which includes water returned to the stream from groundwater discharge after the floods have passed. The value of 0.7 is representative for most of British Columbia, where it has been found that about 30% of the annual runoff occurs as indirect groundwater return to the streams. Thus, for west coast streams an estimate for Phil x Phi2 of 0.56 (0.8 x 0.7) is representative.


Cochrane
Creek
Mount Cochrane
Mount Tapo
MOUNTAI
MOUNTAIN
LF
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MBIA
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96
95

Scale = 1:50,000

Figure 2.1 TOPOGRAPHIC MAP

During most floods the entire area of the catchment does not contribute to the direct runoff which appears in the flood peak. The area which is actually contributing usually varies between 0.4 and 0.6 times the drainage area which is measured from a topographic map. On a given watershed the value is a random variable depending upon previous precipitation. For extreme events on small, steeply sloping catchments and in areas of very high annual precipitation (3000 mm annually) a value of 1.0 is appropriate. This ratio is one of the most important parameters. **FFA** automatically provides an estimate based on a regional analysis developed for **IMP**.

The catchment parameters described above are used by the model to develop estimates of the routing which takes place during storm events and the approximate water balance. However, the driving force behind flood peaks is obviously the rainfall which occurs during an event. Each year there are several hundred rainfall events which occur in coastal watersheds. Detailed analysis of hourly records for several stations in B.C. has shown that the probability distributions of duration, intensity and annual number of events can be estimated solely from their averages.

FFA provides estimates of the average event duration and intensity and the number of rainfall events per year. These estimates were based on an empirical correlation between annual precipitation and the values obtained from an analysis of hourly rainfall at several stations in British Columbia. The values suggested by the program are generally reasonable, however the user may wish to adjust them based on other information about the statistics of individual rainfall events or by comparing flood frequency curves obtained from the program with those obtained from records of runoff on nearby gauged small streams.

FFA deals with rainfall and snowmelt independently and then combines them to produce the overall flood frequency curve. In some cases this is a valid procedure, but for the small hydro watersheds snowmelt is a factor which does not contribute significantly to rare flood peaks. The questions about the duration, intensity and annual number of snowmelt events can be answered by simply pressing return if values are not known. For larger watersheds (500 sq. km and above) hydrologic simulation can be used to identify snowmelt although this capability is not part of **IMP**. The statistics of these events can be used with **FFA** to estimate the effect of snowmelt on the flood frequency curve for larger watersheds.

After all of the data have been entered the program will return you to the function menu (B.11). After you have listed the data (B.13) and edited it to your satisfaction (B.14), you should use

Function 7 to save the data (B.15). An abbreviated form for the watershed name can be used when the file is saved so that you will recognize which file is which at some later date. The flood frequency calculation itself is initiated by selecting Function 6 from the menu. The analysis takes about 5 seconds, and the results are automatically displayed when the calculation is complete (B.16).

5. WATERSHED MODEL DATA

The Watershed Model (B.17) operates from two basic data files. The first is a file of watershed modelling parameters that describe the watershed and the various paths which precipitation takes over land and through the soil. The second contains daily precipitation and maximum and minimum temperature values; these are used to develop estimates of average daily runoff from the watershed parameters through the modelling procedure. **IMP** has a data base which includes parameter files and the meteorological data files for each of the six regions shown on Figure 1.1.

The watershed model operates only in the metric system. Areas are input in square kilometres, elevations are in metres, discharges are in cubic metres per second, and precipitation is in millimetres.

After you have selected the parameter data file (xxxx.PAR) using Option 1 (B.19) you can list it (B.23) to get an idea of the default values which it contains and then you can use the change routine (B.24) to modify the file to make it specific to your watershed. Most of the changes to the data are quite obvious and require no additional comment.

The atmospheric model, **PRECIP**, provides an estimate of the long term average precipitation at the mean elevation of your watershed. However, if there is a significant range of elevations over your basin there will be a precipitation gradient amounting to approximately 4.7 percent (increase) per 100 metres. **BCSIM** has a built-in routine to accommodate this gradient.

To transfer AES data to your watershed, you must relate the precipitation over the project basin to the precipitation at the selected base AES station. This is done using an elevation correction as follows:

$$P_{W\bar{A}ES} = P_{W\bar{A}T} \cdot \left\{ 1 + 0.047 \left(\frac{ELAES - ELWAT}{100} \right) \right\} \qquad (2.1)$$

in which:

P_{WAES} = Average annual precipitation on your watershed adjusted to the elevation of the AES station

P_{WAT} = Average annual precipitation on your watershed derived, for example, from **PRECIP**, adjusted as appropriate (see Table 2.1).

ELAES = The elevation (meters) of the AES station you are using for the hydrologic simulation.

ELWAT = The mean elevation of your watershed.

The value of P_{WAES} will be requested by the data management program **BCMAN** (B.27) when it asks the question:

"Enter long-term avg. precip. at hydro-site:?"

when you enter the data changes routine. Appendix A provides an example .

A watershed can be broken up into several sub-basins (B.28), each with its own hypsometric (area vs. elevation) curve. For small-scale hydro analysis there would normally be only one sub-basin. Working from a topographic map the areas between certain intervals can be estimated by planimetering or counting squares. The hypsometric curve (see Figure 2.2) can then be plotted and from it five bands of equal area can be defined. **IMP** requires exactly five elevation bands and for each of these the mean elevation and the area are entered into the parameter file (B.30, B.31).

The watershed model contains adjustments (B.35) which account for the variation of precipitation with elevation within the watershed (equation 2.1). This internal gradient has been determined from regional precipitation studies for the coastal and interior regions of B.C. and would not normally be modified by you. However, if you wish to take control over the way in which precipitation varies with elevation you can use the Precipitation Adjustment Parameters. The parameters which should be input are positive or negative fractional changes. For example, a value of -0.1 in a specific elevation band would indicate that the desired precipitation in that band is 90 percent of the value automatically computed by the watershed model.

The Water Budget Allocation parameters (B.36, B.37) control the allocation of moisture to the various runoff components. A value of 1.0 for the depressional storage allocation indicates that depressional storage is not being used in the runoff routing. A

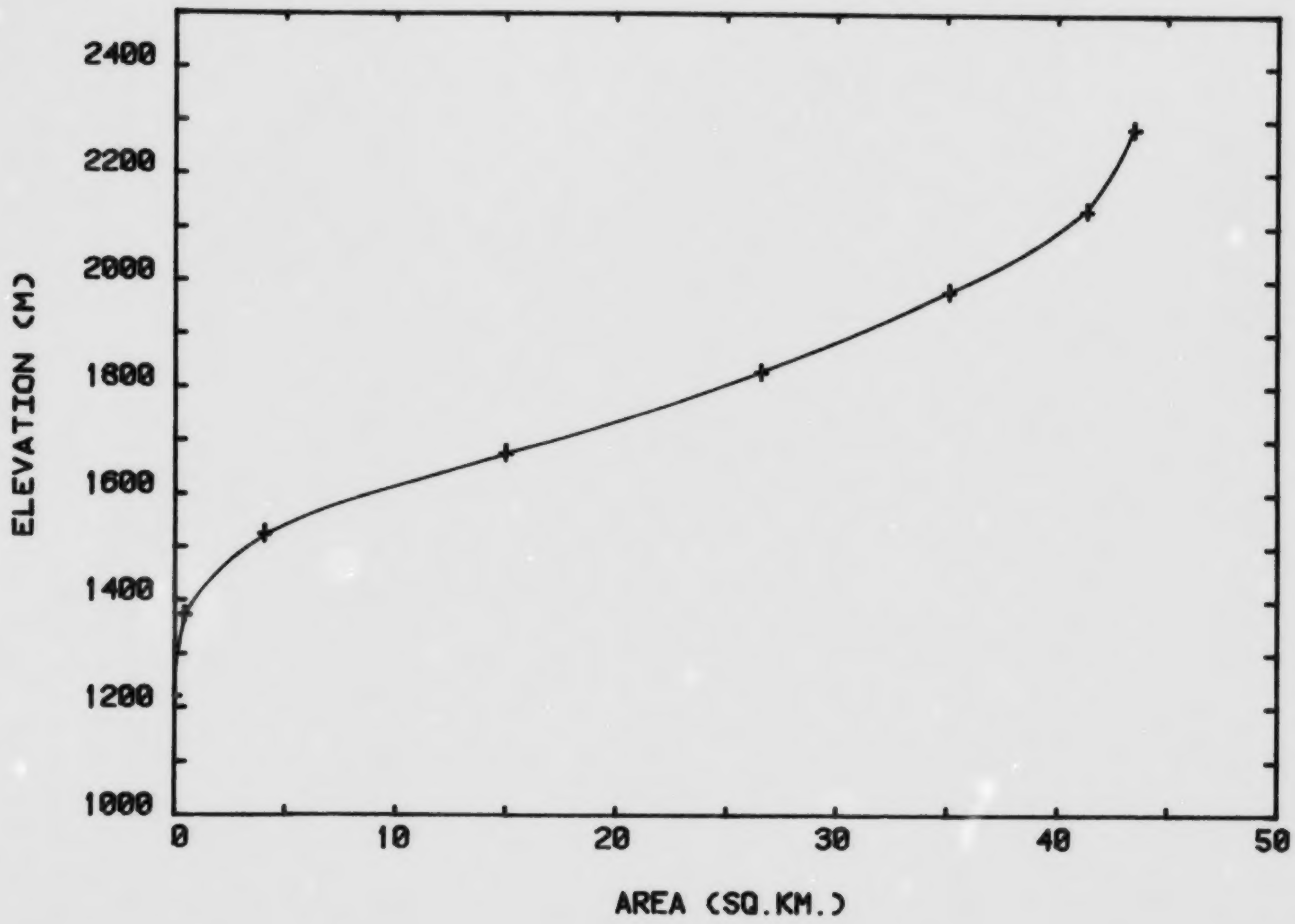


Figure 2.2 HYPSOMETRIC CURVE

value less than one will allocate depressional storage to represent, for example, natural regulation by marshes or lakes within the catchment (B.37).

The fast runoff soil moisture deficit control parameter (B.37) is the value in mm at which 10 percent of the indicated impermeable watershed area occurs. The indicated impermeable area occurs at the soil moisture which causes saturation and between these values there is an exponential shrinkage in the impermeable area as the watershed dries out towards the lower value of 250 mm of water deficit in the root zone. The soil moisture loss threshold uses the same concept to determine the ratio of actual evapotranspiration to potential evapotranspiration. Before groundwater flow can occur soil saturation must be exceeded by the threshold limit for groundwater allocation.

The groundwater flow itself is split between the deep and shallow zones. The deep zone storage allocation indicates the fraction of total groundwater which goes to the deep zone. For example, a value of 0.5 would indicate that the groundwater is equally split between the deep and shallow components. For each of these components a different time constant governs the rate at which it returns to the stream. The values for these parameters shown in the **IMP** parameter file would not normally be changed by the user, because they have been developed from calibration between computed and observed runoff in each of the hydrological regions.

The hydrograph shape is governed primarily by five runoff component time constants. One of them, interflow, is not shown in the menu of changes because for the small watersheds considered here, it behaves essentially like surface runoff. The values for the other four - fast rainfall runoff, fast snowmelt, upper zone groundwater, and deep zone groundwater, can be modified using the change menu (B.38). The values used in the parameter files for each hydrological region were obtained by calibration. The fast runoff time constants vary from 0.1 for a 10 sq. km basin to 0.5 for a watershed area of 1000 sq. km. Values can be interpolated for your watershed within this range.

The option titled Initial Outflow from Deep Zone Groundwater, specifies the base flow level which is prevalent at the beginning of the simulation. This deep zone groundwater outflow may take up to one year of simulation before the effects of the initial value disappear. The value shown (B.39) in the parameter file is a reasonable value to use for the Water Survey of Canada (WSC) gauged catchments included in the **IMP** data base to represent the outflow from the deep zone groundwater on October 1st in most years. **The value shown for the region in which your site is located must be multiplied by the ratio of the drainage area of**

your ungauged hydro site to the drainage area of the representative WSC watershed for your hydrological region.

The importance of the initial value for the deep zone groundwater outflow is different in the interior than it is on the coast. Interior watersheds do not receive significant recharge to the deep zone groundwater after freeze up in the fall, whereas on the coast there is a significant amount of input during the rainy season in the winter. An interior watershed often experiences its lowest runoff in late spring. At that time, a significant proportion of the total flow in the stream will be coming from deep zone groundwater which has finally percolated through to the stream. The initial value chosen during the previous October may have significant influence on the total amount of water which appears in the stream at that time. Thus, in analyzing the power potential of watersheds of this type, it may be important to carry on the simulation for more than one year to reduce the importance of assumptions about this deep groundwater outflow initialization value.

After you have made the changes necessary to describe your watershed in the parameter file remember to save the results (B.40). **BCSIM** will automatically add the extention .BCM to the file name which you use. Choose a name for the file which you will recognize later when you go to run the actual simulation.

6. USING THE WATERSHED SIMULATION MODEL, (BCSIM)

The program (B.41) contains two questions which are of little interest to people doing power studies but may be useful to hydrologists undertaking research. After you have selected the parameter file describing your watershed, the program will ask you if you want to use the Water Survey of Canada (WSC) data file for calibration (B.42). You should generally respond "No" to this question. The progam next requests the name of the Atmospheric Environment Service (AES) station which is representative of your hydrologic region (B.43). When you have selected the appropriate file number from the choices on the screen the program will ask if you want detailed output for calibration. Again you should respond negatively (N).

When the program asks you if you would like the Synthetic Flow Output be sure to respond "Yes" (B.43), otherwise you will receive no output from your analysis. You should use a file name for this output which you can readily identify later when you wish to look at it using **GAP**. The output is in cubic metres per second for water years beginning Oct. 1. (i.e. 1976 water year extends from October 1, 1976 to September 30, 1977).

When the program starts simulating it will first give you the clock time at which it started and then ten lines of output to confirm that it is working with the correct data file and that it is planning to execute the appropriate number of time steps (B.44). The five columns of confirmation information are:

1. The year, month and day.

2. The Water Survey of Canada reference flows. These would normally be 0 since you have not requested that they be accessed.

3. The maximum daily temperature in degrees Celsius.

4. The minimum daily temperature in degrees Celsius.

5. The total daily precipitation in millimetres.

The program will not simulate a period of record less than one year. Running on an IBM-PC-XT with an 8087 co-processor it takes approximately five minutes to simulate 365 days. When the simulation is complete the program will briefly display the ending clock time and then return to the master **IMP** menu. From there you can examine the output using **GAP**.

7. PREPARING THE DATA FOR A POWER STUDY

POP1 (B.45) is a program that helps you set up and modify the data for analyzing the hydroelectric potential of your site. The program allows you to input data, save it, retrieve it, and to make changes to it.

The program first (B.49) asks you to input a title for your data set. This title appears on all of the output and you should choose one that is brief so that there will be room for it on the various tables and graphs but complete enough to identify the file and date of the analysis.

If your project has a reservoir (B.49) the program assumes that the penstock intake is connnected directly to it. During the calculation of energy production the net head accounts for drawdown in the reservoir and all controlled releases are assumed by the program to pass through the penstock and powerhouse. If you have more than one reservoir or a reservoir that is located some distance upstream from the penstock intake you may be able to approximately model your configuration by aggregating the upstream storage, selecting an appropriate stage-storage curve, and defining appropriate operating rules for use of the storage during the year.

If there is some portion of a period of record which is known to be especially important to you, for example a period of known very low runoff or very high energy demand, you can identify it as the Firm Energy period (B.50). During the simulation the program will separately identify the energy produced during this period.

If you have a reservoir the program will request information describing it and its operation (B.51). The reservoir name should be kept brief and since this version of the program will only accomodate a single reservoir there will always be a power station associated with it. Reservoir levels are in units of elevation (i.e. feet or metres), and storage is in consistent units of daily flow volume (i.e., cfs-days, or cms-days) (B.52). The full range of possible reservoir storage volumes should be covered by points on the stage-storage curve (B.55). The program will interpolate between points which you specify so a minimum of two is required. You must specify a "dead" storage pocket below the elevation of the intake. The pocket can be small but if it is not specified the program will not always operate properly.

The rated discharge capacity of the powerhouse is the maximum total flow which the turbine set can pass at the rated net head. The turbine capacity should be carefully matched to the hydraulic capability of the penstocks. Turbine flow should be specified in consistent units (cms or cfs) (B.56). You can define the rated head (in metres or feet) for the powerhouse by subtracting estimated penstock losses and tailwater at the rated discharge from the maximum gross head.

Both the penstock length and its diameter are entered in consistent units, (either metres or feet) (B.57). Friction losses in the penstock are calculated in the program using the Manning's equation. The user should select an effective length that reflects minor losses (bends, joints, etc.).

The operation of the reservoir is controlled by the maximum and minimum monthly target reservoir levels and the maximum monthly powerhouse operating turbine flows (B.58). The reservoir levels are used by the program as a guide for drawdown and refill in accordance with the hydrologic behaviour of the watershed.

The target minimum reservoir elevations (month and storage levels) in each reservoir and the target controlled releases (B.59) for each reservoir are the essential elements in the reservoir operating scheme in the **POP** simulation model. These parameters are interrelated and should be developed with this in mind. The amount of water that can be released on any day depends upon the water available in storage and the inflow. The two targets can be in conflict if there is not enough water to satisfy both. If the target release is too high then it may not be possible to meet the target reservoir level. Workable combinations of the two targets is dependent on hydrology and the live storage volume and how it will be used to regulate the flow. The ability to select appropriate targets will develop as the user gains experience modelling the project under study. In this section, some suggestions are made for developing a trial set of targets.

The basic purpose of a storage reservoir is to store water from the wet season for use in the dry season. Using this simple concept, a hand calculation of the reservoir routing of the annual hydrograph of mean monthly flows gives a good indication of what the appropriate targets should be. The year can be divided into wet and dry seasons based on whether or not the monthly average flow is above or below the annual average (see Figure 2.3). Compute the average flow for the dry season and add

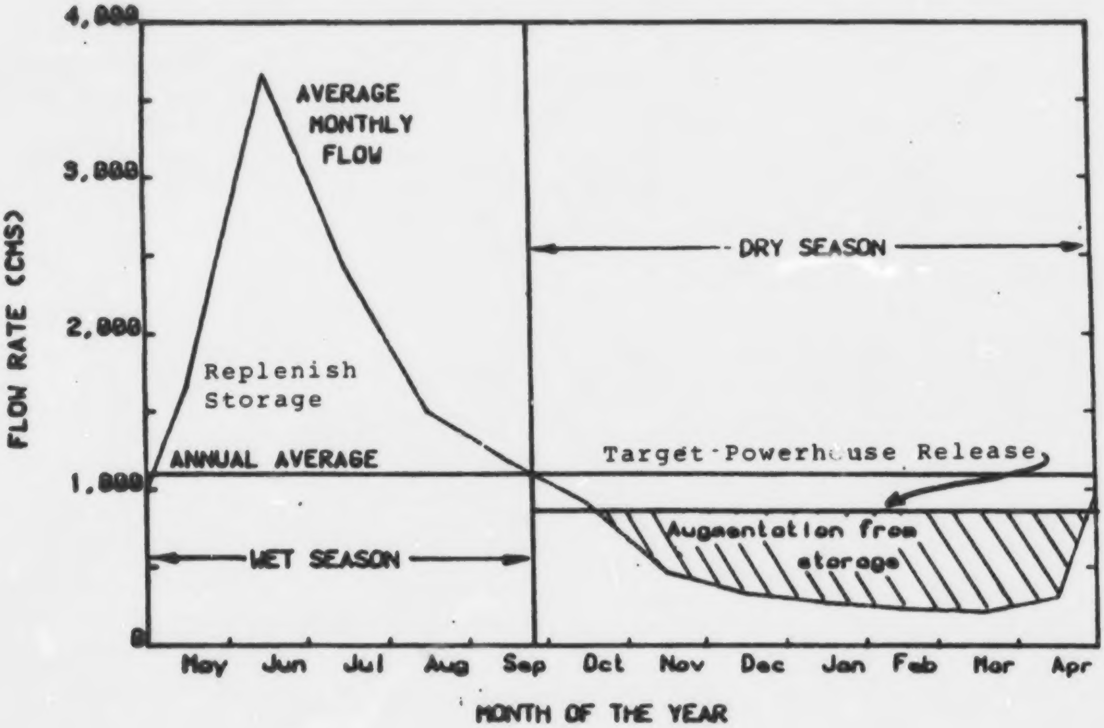


Figure 2.3 FIRST-CUT ESTIMATES OF TARGET RELEASES

the amount of live storage in the reservoir to obtain the desired dry season average flow by augmentation from storage. This is a good starting estimate of the target controlled release for the dry season. Note that the target controlled release should never be more than the annual average runoff, otherwise over-year storage is used continuously and this will eventually cause the reservoir to empty and never refill.

The appropriate target minimum reservoir elevations can be determined from the volume of the target controlled release which must come out of storage in each month. Assume the reservoir is empty at the end of the dry season; then calculate backwards in time to determine the levels required at each month. A similar procedure can be used to develop the target minimum reservoir elevations during filling.

The target controlled releases and minimum elevations for reservoirs with regulation upstream can be developed in exactly the same manner if it is assumed that the upstream reservoirs provide perfect control of their runoff. Thus the downstream reservoir has only to regulate the unregulated intermediate inflow.

For reservoirs that are to operate run-of-river, a different approach is required. Basically, these reservoirs are always full and simply pass the inflow. Therefore, the target release would be the powerhouse capacity (provided that the penstock is large enough) and the target elevation is the full supply level throughout the year.

The maximum powerhouse turbine flows (B.58) are more than a guide; they are the absolute maximum releases through the powerhouse. If the reservoir is full and an additional release is required, it will bypass the powerhouse and appear as spill in the simulation results. You can use these limits on powerhouse discharge capability to test the effects of scheduled maintenance or other factors which may seasonally limit the discharge capability.

The target controlled flows (B.59) provide additional guidance to the program where flexibility in operations is possible. The program normally will ensure that powerhouse flows are at least as great as the targets.

The maximum allowable (powerhouse) releases (B.60) would normally not be exceeded by powerhouse discharges. However, if the reservoir is full, the powerhouse may operate up to its discharge capacity if it is possible to avoid some of the spill.

The total flow below the powerhouse, the sum of the powerhouse discharge and the spill, may increase tailwater levels on the plant. The variation in tailwater elevation with discharge defines the tailwater curve (B.61, B.62). Values should be input in consistent units (cfs and feet, or cms and metres). The net head on the plant will be calculated by interpolation between the values specified. If a single point is given, its elevation will be used for all discharges.

A number of curves for turbine efficiencies have been included in the data base. You can select one of these curves (B.65) or enter your own (B.64).

When you have finished inputting the data be sure that you save it using Option 5 in the **POP1** menu before you turn off the machine or move on to another program in **IMP** (B.70). You can list (B.67) the data on the screen and revise the obvious errors (B.68, B.69) in input before running a copy out to the printer.

8. MODELLING THE PROJECT OPERATION

POP2 (B.71) is the routine which does the day by day simulation to determine energy production from the project.

The program does not consider diurnal variations in power demand or the integration of the hydro capability with other energy sources.

POP1 and **POP2** operate with either English or Metric data. However, the streamflow data provided by **IMP** are always metric. **POP2** determines the units that you wish to use from the project configuration file created by **POP1** and asks that you confirm the units of the streamflow data (B.74). If you are working in English units **POP2** will convert the metric discharge data appropriately. If the user believes that streamflow at the project site differs from the regional streamflow provided in the **IMP** data base, a prorating factor (B.74) can be applied to adjust the streamflow (xxxx.WSC) records accordingly.

Execution of the program will take about 30 seconds or less for each year of the simulation. The program will display a brief summary of the energy computed (B.75) and, after you have touched any key, return the user to the **IMP** master menu.

9. CHOOSING THE OPTIMUM INSTALLED CAPACITY

POP3 (B.76) performs a simple incremental analysis on the results of the simulation of your chosen project configuration. The program examines the spill which could be captured or created if the powerhouse capacity was changed within specified lower and upper limits which you wish to examine. The resulting increase or decrease in energy generation is used as the basis for calculating the marginal value and cost and where these are equal (ratio = 1) the optimum installed capacity is indicated. You may find this program useful in suggesting whether you have correctly matched the powerhouse capacity to the hydrologic capability of the site and the penstock dimensions. If the hydrologic data is limiting energy output you will notice a gradual increase in annual energy production as powerhouse discharge capacity is increased. The point at which the penstock hydraulic losses limit energy production will be shown at the discharge where annual energy production becomes a maximum.

The optimum capacity (B.82) is at the point where the ratio of the marginal value to the marginal cost is 1.00.

When you have examined the output you may decide to examine the optimum installed capacity more closely by reducing the range of capacities which the program should examine. There are no files created by this program but you can save the output table by directing it to the printer.

10. EXAMINING THE DATA AND RESULTS

GAP (B.83) is a handy utility program that will plot your data and results, and will perform frequency analysis. It will deal with output from simulations using **POP** or the watershed model, and data which is stored in the standard format of the Water Survey of Canada (WSC) and the Atmospheric Environment Service (AES) (B.84).

Time series data, such as energy, varies from one day to the next. Because the size of the screen is limited, **GAP** will display one year of daily time series data at a time. To go on to the next year you simply touch any key; to stop the plotting touch the letter "S" and the program will ask if you want to examine some other variable for the current year (B.92).

The program will tell you the range covered by the data which you wish to plot and you must choose appropriate values for the maximum and minimum scales on the graphs. These must be integer values. If your hydro project is very small and you have chosen to use metric units, some values, such as powerhouse discharge, will often be less than one and it will not be possible to plot the results with **GAP**. In this case you should go back and input the data using **POP1** in English units. Do not choose the same values for the maximum and minimum or the program may experience an error when it attempts to set up the scales for the plots.

You can elect to plot AES data (maximum and minimum temperature and precipitation) all on the same screen (B.94, B.95). If there is an additional year or more of data the program will go to it automatically if you touch any key after all four variables have been plotted. If instead you would like to stop and look again at the result for the current year you should touch "S".

A frequency analysis on the time series data can be performed for a single year or for groups of months (seasons) which cover the entire period of record (B.108). For example, if you are interested in the energy production only during the month of July you would select the seasonal frequency option. If the analysis conducted by **POP2** covered a ten year period of record the frequency option would examine all ten sets of July energy as if it was one continuous data series. The frequency histogram and the energy duration curve would then be calculated on these 310 values of July energy production. Up to four contiguous months may be grouped together in this way to determine seasonal frequency and duration curves.

You can select the points on the frequency and duration curves spaced at equal intervals on either a linear or logarithmic scale (B.109). If you choose the log scale there will be better resolution at the lower values. You can see this by selecting the logarithmic option and printing the frequency table on the screen. The difference between the minimum and maximum values in this table is broken into ten increments (B.111). The first two columns show the interval covered by each increment. The third column is the mid-point of the increment and the fourth column is this point divided by the mean. The number of values which fall in this interval is shown in the last column and this determines the percentage frequency of occurrence in the interval. The sixth column is the cummulative sum of the frequencies below the upper limit of the current interval. The probability density is the absolute frequency (not percentage) divided by the width of the interval. The maximum, minimum, mean, and standard deviation are shown at the bottom of the table.

If there are more than five values exactly at the minimum or maximum the program will assign a probability impulse to that value. This defines a mixed probability distribution and in this case the table will separate the values at the impulses from the continuous probability distribution in the body of the table.

If you decide to plot the frequency distribution you should leave some space at the top by chosing a maximum value for the plot somewhat greater than the actual maximum shown for the data (B.112). This will leave room for some tabular information which is superimposed upon the graph. If you are not satisfied with the appearance of the plot the program will give you an opportunity to rescale and draw it again.

The duration curve shows how frequently the variable on the x axis is exceeded (B.114). You will probably notice that the shape of the flow duration curve is often quite different from the shape of the energy duration curve. This difference simply emphasizes the importance of head losses in the penstock and drawdown in the reservoir.

If you match the reservoir and powerhouse capacity poorly with the available runoff the simulation results will be correspondingly disappointing. It is necessary to choose your power study variables in a consistently logical way and you should develop a standard procedure for systematically plotting results while ranging over the capacity of the project components.

11. KEEP IN TOUCH

Please write down your impressions as you gradually become familiar with **IMP** and send them to us. We would welcome your suggestions for improving the package.

APPENDIX A

EXAMPLE OF PRECIPITATION ESTIMATING PROCEDURE

Latitude	50° 03'
Longitude	132° 02'

Watershed elevation Top = 780 m Bottom = 15 m

Mid-Area Elevation of Basin = 270 m

Regional AES Station (Tasu Sound) Elevation = 15 m (Table 1)

Modelling Region (1) Adjustment Factor (Table 2) = 2.0

PRECIP grid points (mm)

1549	1422
2082	1905

Interpolated Average Annual Precip = 1880 mm
(centroid of lower half of 10 minute square)

Average Watershed Precip = 1380 mm x 2.0 = 3760 mm

Adjustment to AES Elevation (Tasu Sound), Equ. 2.1

$$\overline{P}_{WAES} = \overline{P}_{WAT} \times \quad 1 + 0.047 \left(\frac{15-270}{100}\right)$$

$$\overline{P}_{WAES} = 3760 \times (0.88) = 3309 \text{ mm}$$

The Precipitation Transposition section of the Changes section of **PRECIP** will ask, "Enter long-term avg. precip. at hydro-site:?" In this case the response would be 3309, and the AES station selected would be TASU.

As a result of the above, **BCMAN** the program will calculate and store the new tranposition factor as:

$$\frac{3309}{4218} - 1 = - 0.215$$

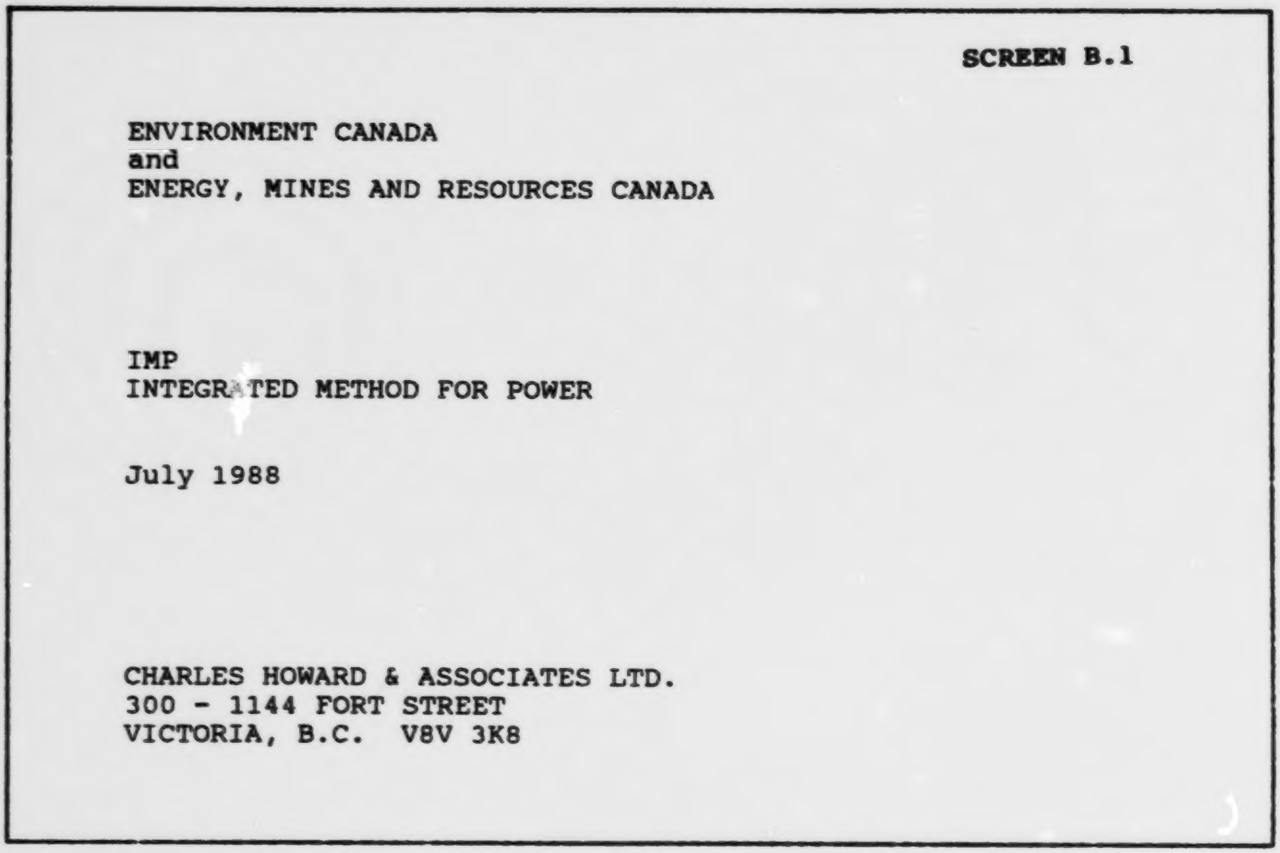
using the value 4218 mm from Screen A2.27.

APPENDIX B

EXAMPLE SCREENS

from

IMP



SCREEN B.1

ENVIRONMENT CANADA
and
ENERGY, MINES AND RESOURCES CANADA

IMP
INTEGRATED METHOD FOR POWER

July 1988

CHARLES HOWARD & ASSOCIATES LTD.
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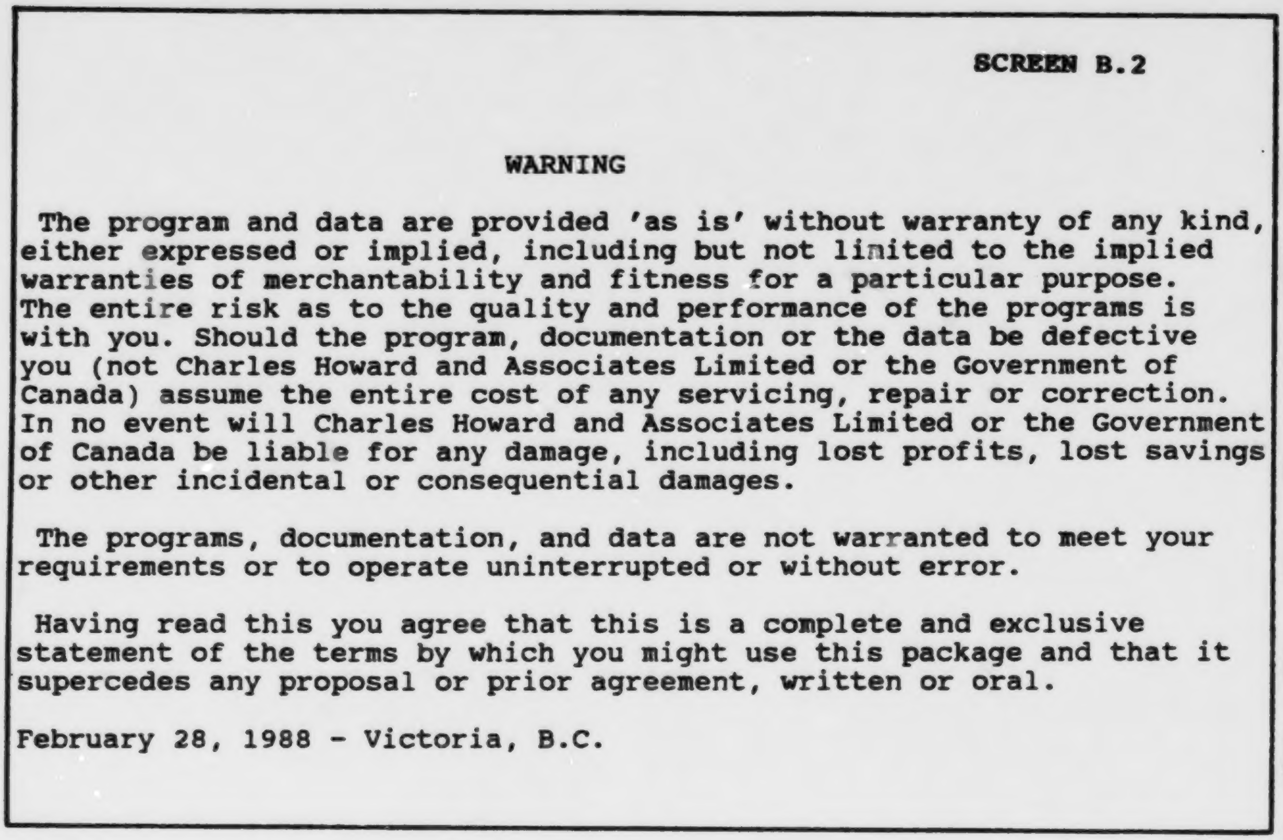
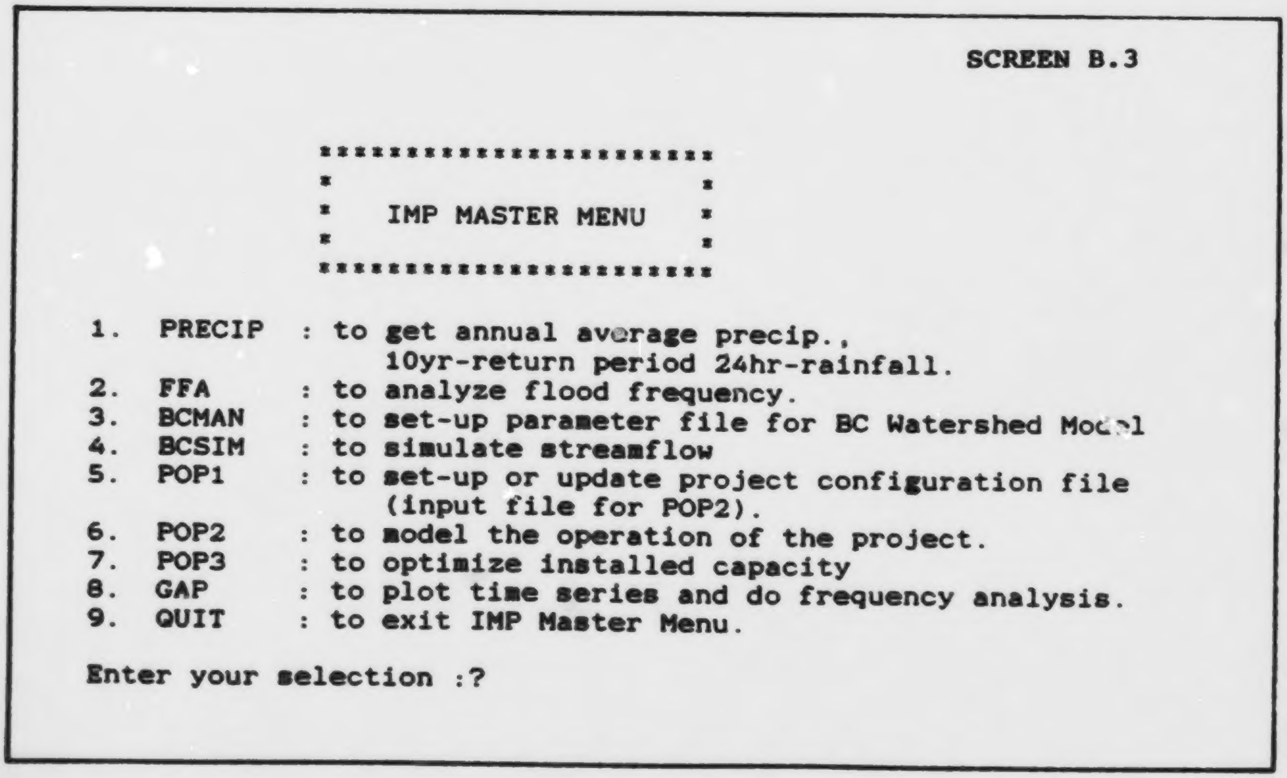
VICTORIA, B.C. V8V 3K8



```
                                                    SCREEN B.2

                              WARNING

 The program and data are provided 'as is' without warranty of any kind,
either expressed or implied, including but not limited to the implied
warranties of merchantability and fitness for a particular purpose.
The entire risk as to the quality and performance of the programs is
with you. Should the program, documentation or the data be defective
you (not Charles Howard and Associates Limited or the Government of
Canada) assume the entire cost of any servicing, repair or correction.
In no event will Charles Howard and Associates Limited or the Government
of Canada be liable for any damage, including lost profits, lost savings
or other incidental or consequential damages.

 The programs, documentation, and data are not warranted to meet your
requirements or to operate uninterrupted or without error.

 Having read this you agree that this is a complete and exclusive
statement of the terms by which you might use this package and that it
supercedes any proposal or prior agreement, written or oral.

February 28, 1988 - Victoria, B.C.
```



```
                                                    SCREEN B.3


              ***********************
              *                     *
              *   IMP MASTER MENU   *
              *                     *
              ***********************

   1.  PRECIP  : to get annual average precip.,
                    10yr-return period 24hr-rainfall.
   2.  FFA     : to analyze flood frequency.
   3.  BCMAN   : to set-up parameter file for BC Watershed Model
   4.  BCSIM   : to simulate streamflow
   5.  POP1    : to set-up or update project configuration file
                    (input file for POP2).
   6.  POP2    : to model the operation of the project.
   7.  POP3    : to optimize installed capacity
   8.  GAP     : to plot time series and do frequency analysis.
   9.  QUIT    : to exit IMP Master Menu.

   Enter your selection :?
```

SCREEN B.4

```
PRECIP
A DATA RETRIEVAL PROGRAM


July 1988




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```
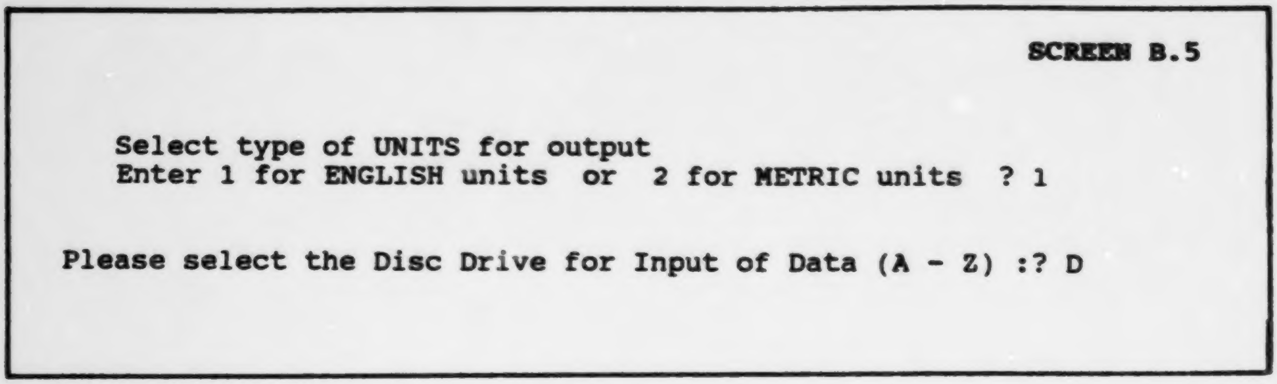
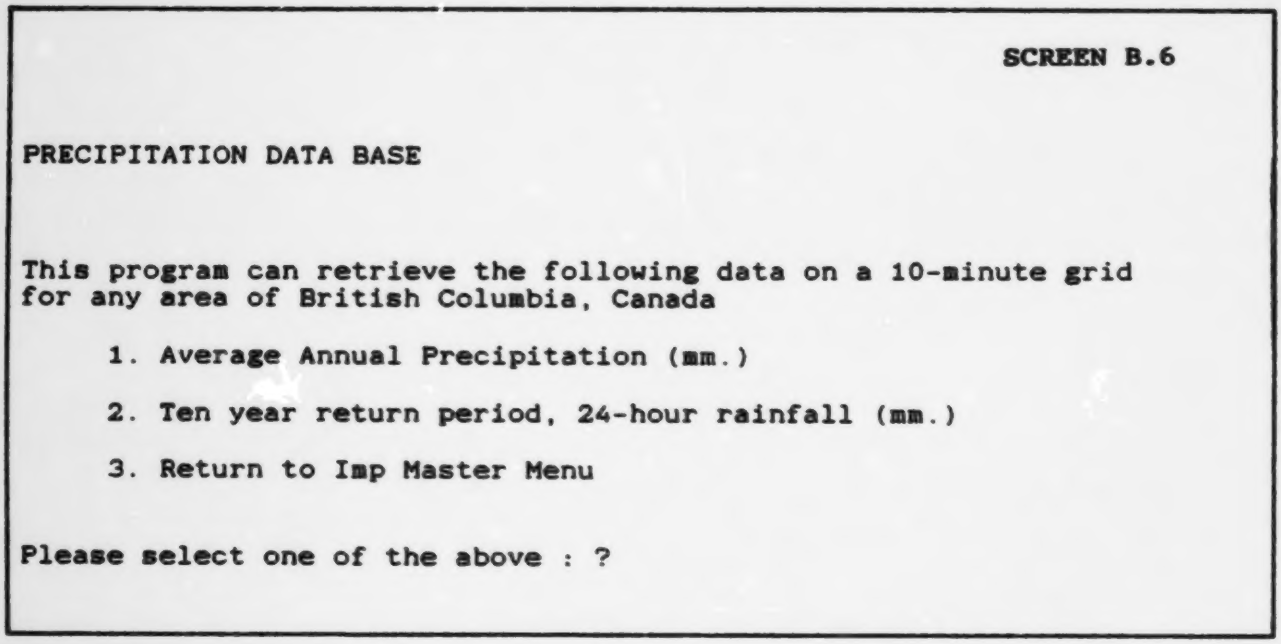



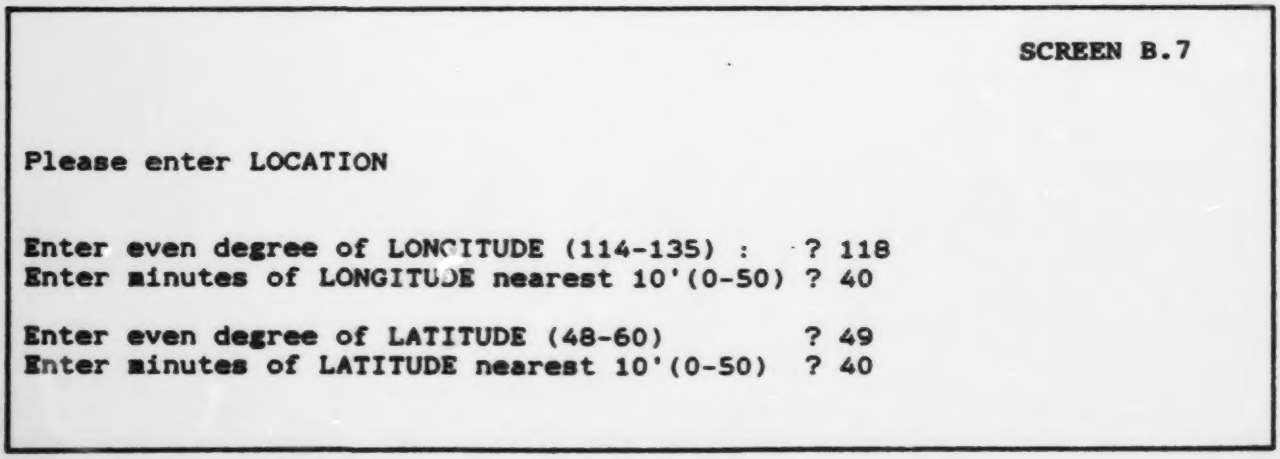
SCREEN B.5

```
    Select type of UNITS for output
    Enter 1 for ENGLISH units  or  2 for METRIC units  ? 1


  Please select the Disc Drive for Input of Data (A - Z) :? D
```



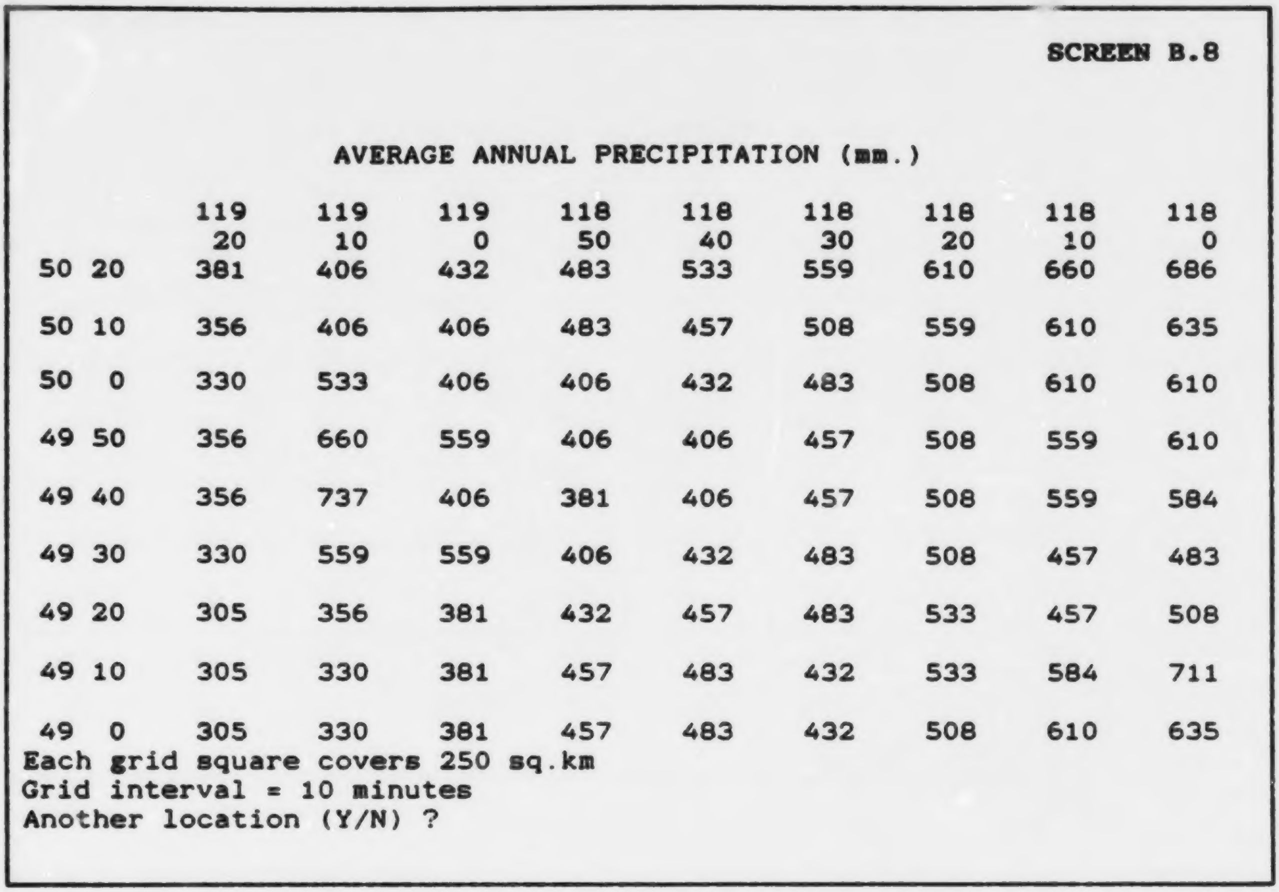
SCREEN B.6

```
PRECIPITATION DATA BASE


This program can retrieve the following data on a 10-minute grid
for any area of British Columbia, Canada

    1. Average Annual Precipitation (mm.)

    2. Ten year return period, 24-hour rainfall (mm.)

    3. Return to Imp Master Menu

Please select one of the above : ?
```

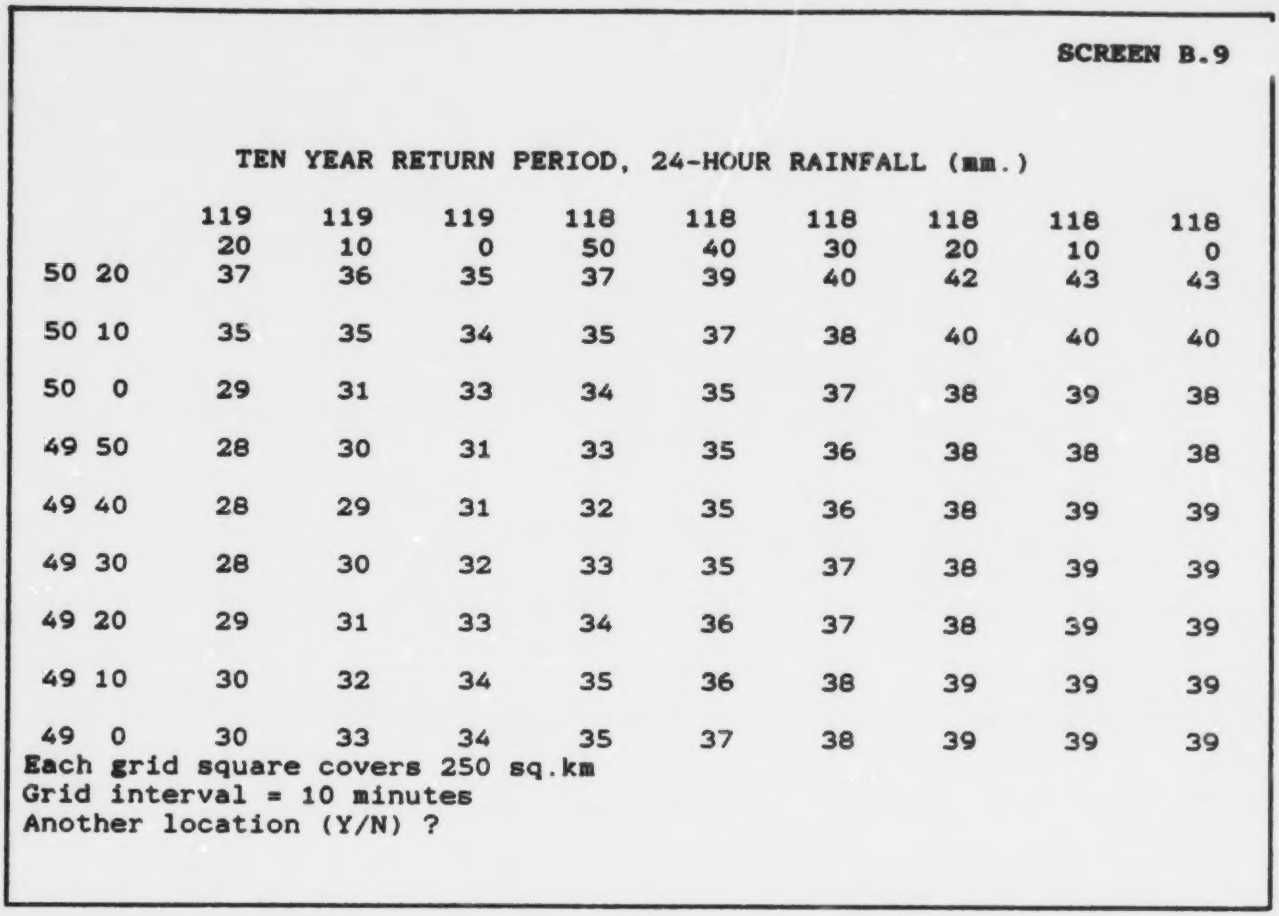


SCREEN B.7

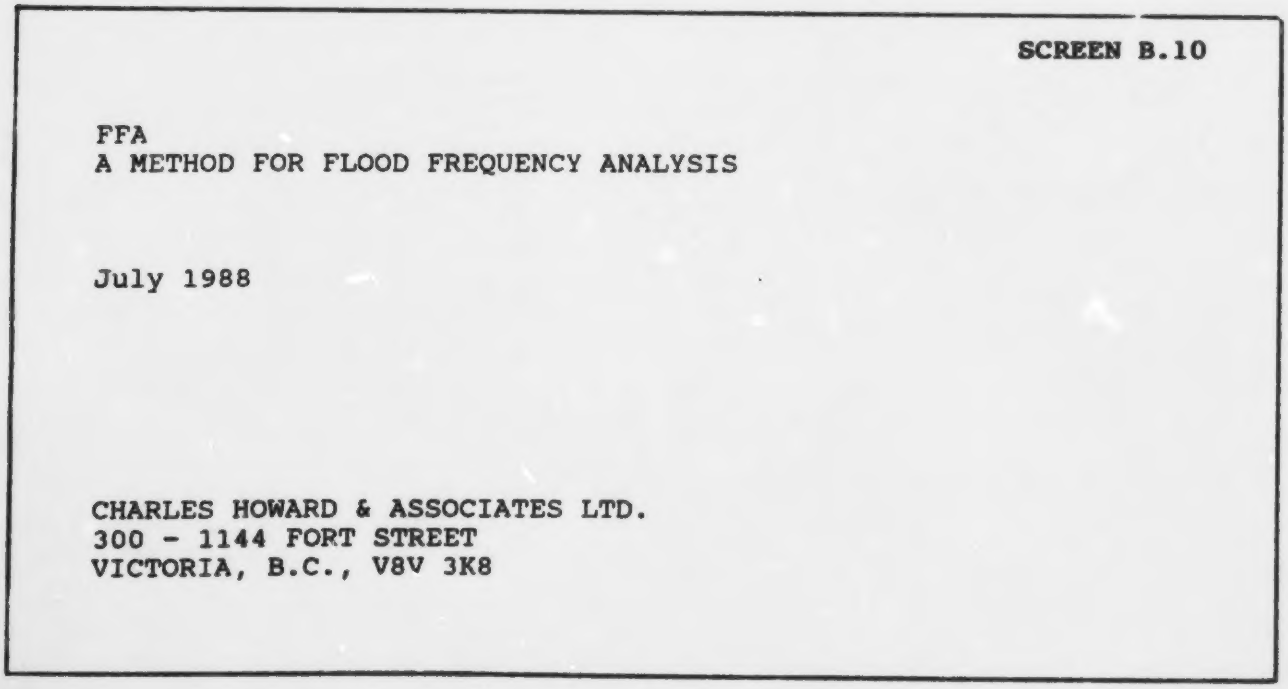
```
Please enter LOCATION


Enter even degree of LONGITUDE (114-135) :   ? 118
Enter minutes of LONGITUDE nearest 10'(0-50) ? 40

Enter even degree of LATITUDE (48-60)        ? 49
Enter minutes of LATITUDE nearest 10'(0-50)  ? 40
```



```
                                                                    SCREEN B.8


                         AVERAGE ANNUAL PRECIPITATION (mm.)

           119     119     119     118     118     118     118     118     118
            20      10       0      50      40      30      20      10       0
 50 20     381     406     432     483     533     559     610     660     686

 50 10     356     406     406     483     457     508     559     610     635

 50  0     330     533     406     406     432     483     508     610     610

 49 50     356     660     559     406     406     457     508     559     610

 49 40     356     737     406     381     406     457     508     559     584

 49 30     330     559     559     406     432     483     508     457     483

 49 20     305     356     381     432     457     483     533     457     508

 49 10     305     330     381     457     483     432     533     584     711

 49  0     305     330     381     457     483     432     508     610     635
Each grid square covers 250 sq.km
Grid interval = 10 minutes
Another location (Y/N) ?
```



```
                                                              SCREEN B.9


              TEN YEAR RETURN PERIOD, 24-HOUR RAINFALL (mm.)

             119    119    119    118    118    118    118    118    118
              20     10      0     50     40     30     20     10      0
   50 20      37     36     35     37     39     40     42     43     43

   50 10      35     35     34     35     37     38     40     40     40

   50  0      29     31     33     34     35     37     38     39     38

   49 50      28     30     31     33     35     36     38     38     38

   49 40      28     29     31     32     35     36     38     39     39

   49 30      28     30     32     33     35     37     38     39     39

   49 20      29     31     33     34     36     37     38     39     39

   49 10      30     32     34     35     36     38     39     39     39

   49  0      30     33     34     35     37     38     39     39     39
Each grid square covers 250 sq.km
Grid interval = 10 minutes
Another location (Y/N) ?
```



```
                                                          SCREEN B.10


    FFA
    A METHOD FOR FLOOD FREQUENCY ANALYSIS



    July 1988






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```
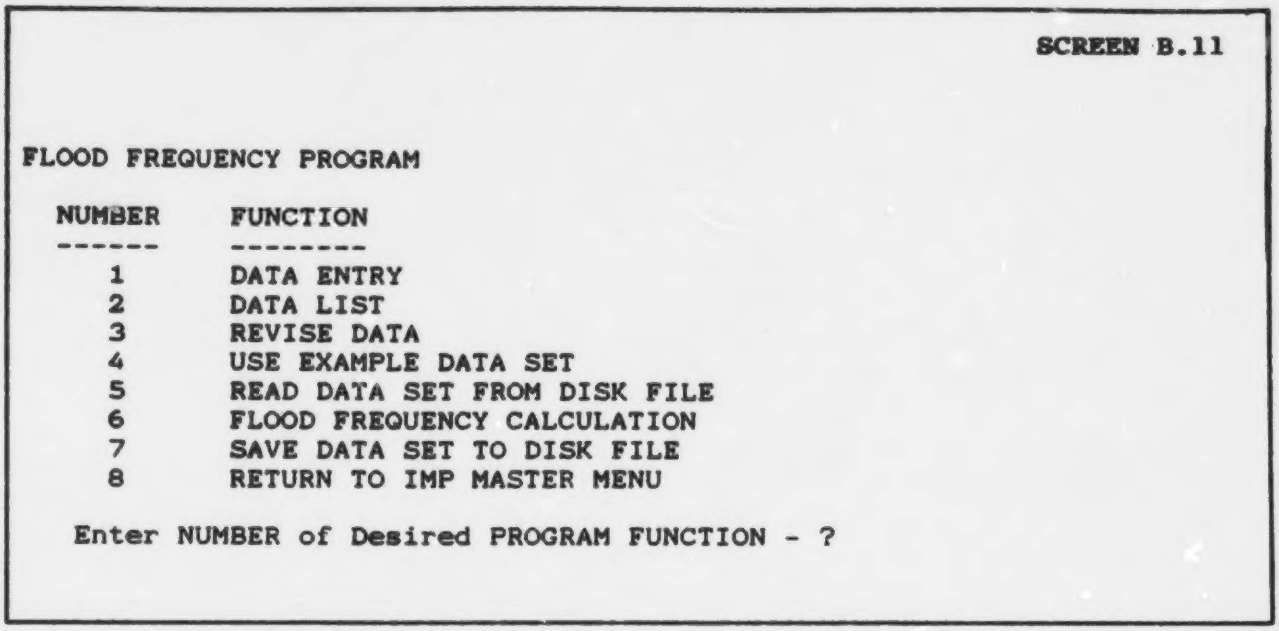
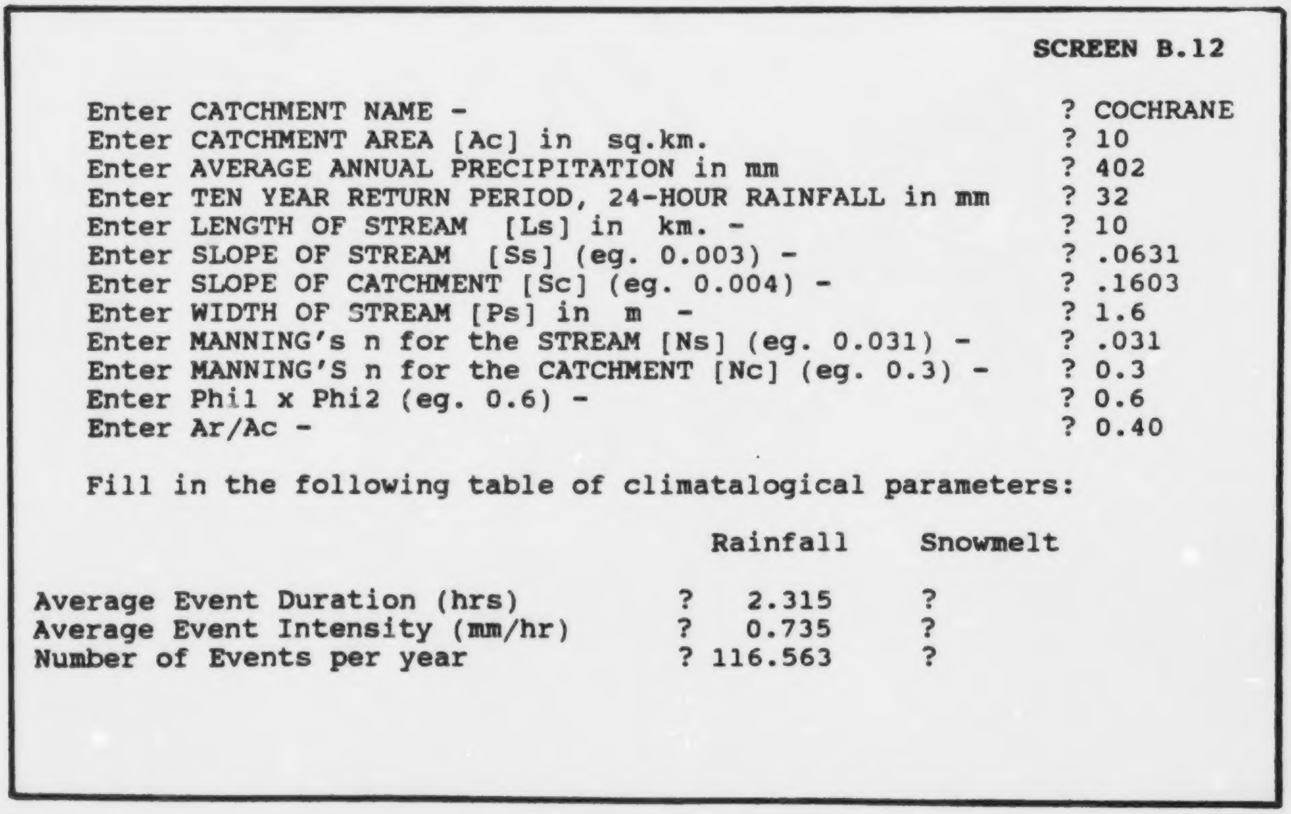
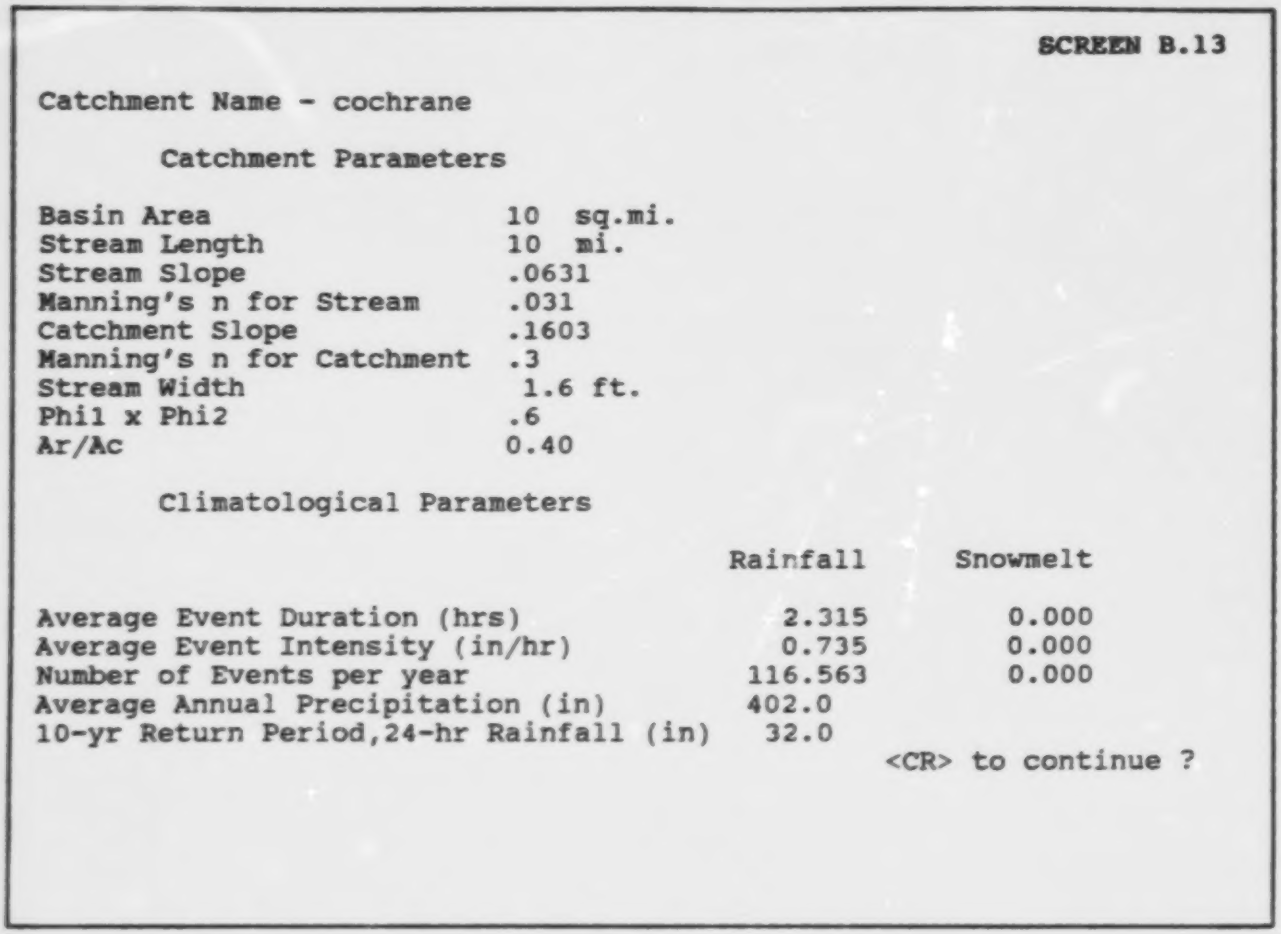



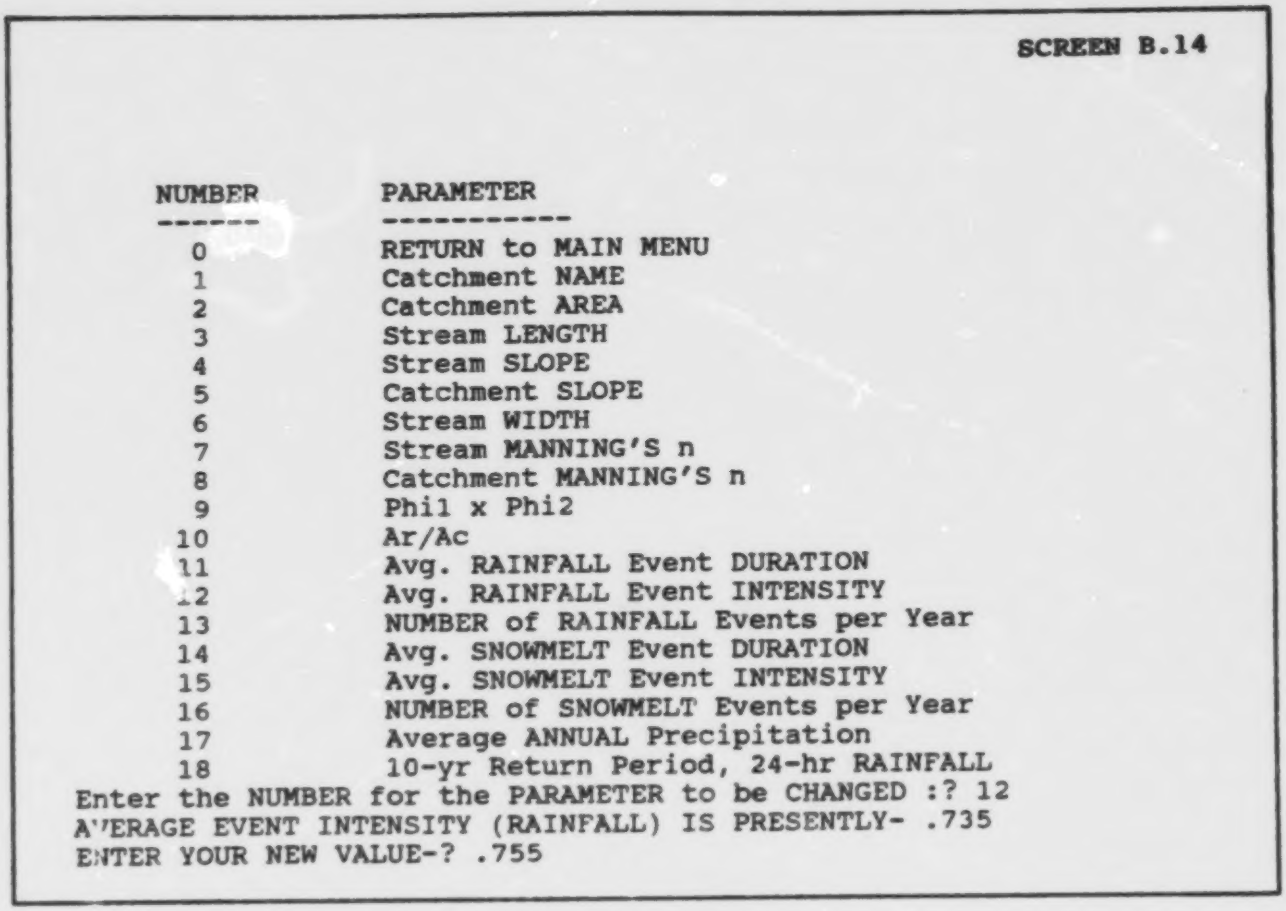
```
                                                      SCREEN B.11


FLOOD FREQUENCY PROGRAM

  NUMBER    FUNCTION
  ------    --------
     1      DATA ENTRY
     2      DATA LIST
     3      REVISE DATA
     4      USE EXAMPLE DATA SET
     5      READ DATA SET FROM DISK FILE
     6      FLOOD FREQUENCY CALCULATION
     7      SAVE DATA SET TO DISK FILE
     8      RETURN TO IMP MASTER MENU

   Enter NUMBER of Desired PROGRAM FUNCTION - ?
```



```
                                                          SCREEN B.12

   Enter CATCHMENT NAME -                                  ? COCHRANE
   Enter CATCHMENT AREA [Ac] in  sq.km.                    ? 10
   Enter AVERAGE ANNUAL PRECIPITATION in mm                ? 402
   Enter TEN YEAR RETURN PERIOD, 24-HOUR RAINFALL in mm    ? 32
   Enter LENGTH OF STREAM  [Ls] in  km. -                  ? 10
   Enter SLOPE OF STREAM  [Ss] (eg. 0.003) -               ? .0631
   Enter SLOPE OF CATCHMENT [Sc] (eg. 0.004) -             ? .1603
   Enter WIDTH OF STREAM [Ps] in  m  -                     ? 1.6
   Enter MANNING's n for the STREAM [Ns] (eg. 0.031) -     ? .031
   Enter MANNING'S n for the CATCHMENT [Nc] (eg. 0.3) -    ? 0.3
   Enter Phi1 x Phi2 (eg. 0.6) -                           ? 0.6
   Enter Ar/Ac -                                           ? 0.40

   Fill in the following table of climatalogical parameters:

                                       Rainfall    Snowmelt

Average Event Duration (hrs)         ?   2.315     ?
Average Event Intensity (mm/hr)      ?   0.735     ?
Number of Events per year            ? 116.563     ?
```

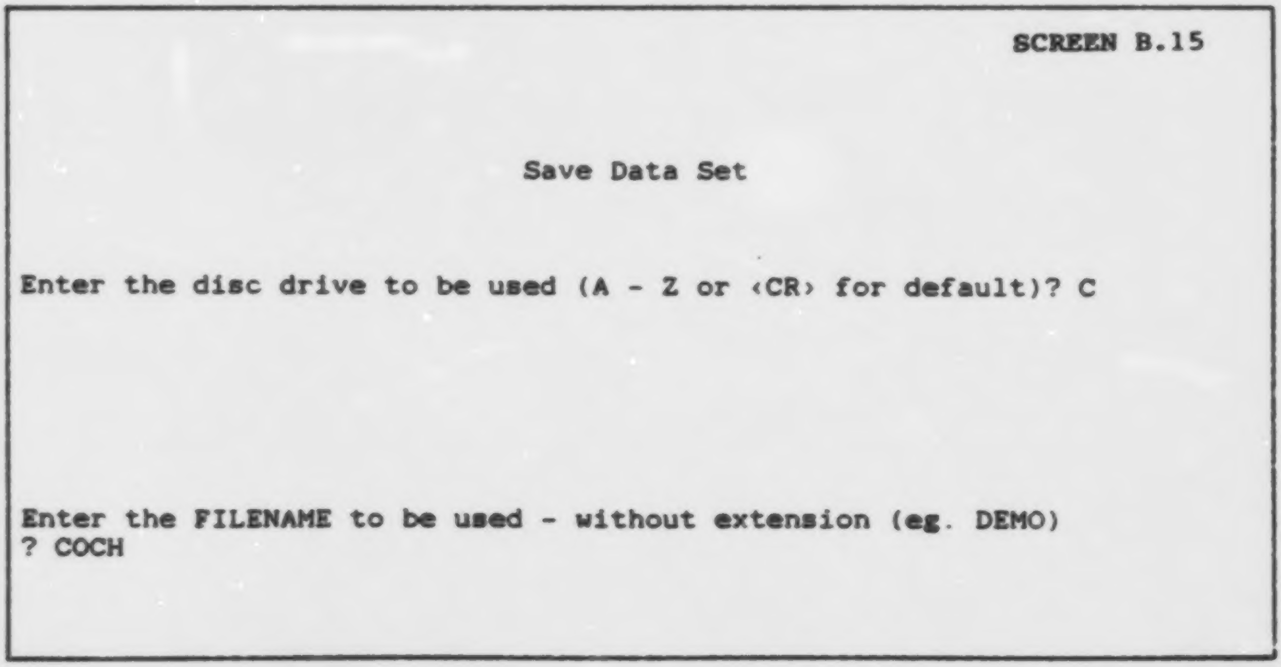


```
                                                                   SCREEN B.13

Catchment Name - cochrane

       Catchment Parameters

Basin Area                   10  sq.mi.
Stream Length                10  mi.
Stream Slope                 .0631
Manning's n for Stream       .031
Catchment Slope              .1603
Manning's n for Catchment    .3
Stream Width                  1.6 ft.
Phi1 x Phi2                  .6
Ar/Ac                        0.40

       Climatological Parameters

                                                Rainfall      Snowmelt

Average Event Duration (hrs)                       2.315         0.000
Average Event Intensity (in/hr)                    0.735         0.000
Number of Events per year                        116.563         0.000
Average Annual Precipitation (in)                402.0
10-yr Return Period,24-hr Rainfall (in)           32.0
                                                         <CR> to continue ?
```



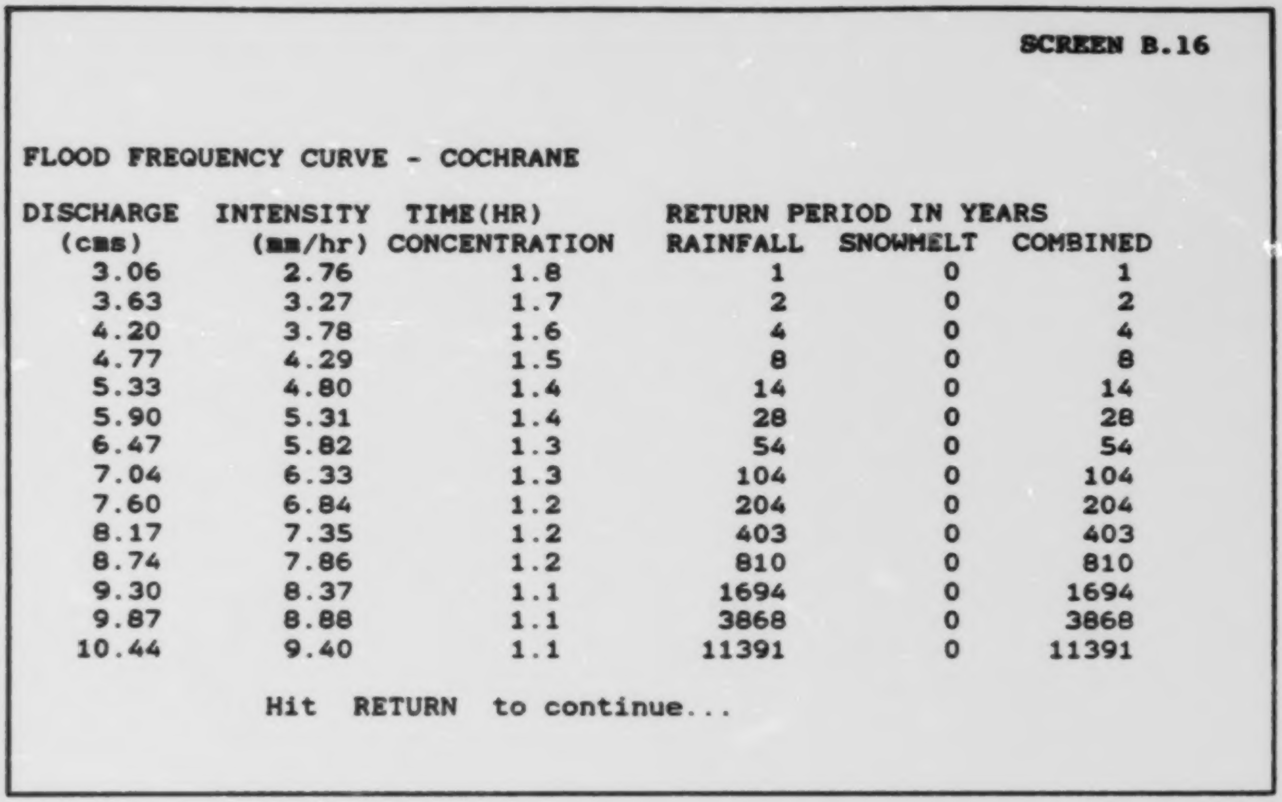
SCREEN B.14

```
        NUMBER          PARAMETER
        ------          -----------
           0            RETURN to MAIN MENU
           1            Catchment NAME
           2            Catchment AREA
           3            Stream LENGTH
           4            Stream SLOPE
           5            Catchment SLOPE
           6            Stream WIDTH
           7            Stream MANNING'S n
           8            Catchment MANNING'S n
           9            Phi1 x Phi2
          10            Ar/Ac
          11            Avg. RAINFALL Event DURATION
          12            Avg. RAINFALL Event INTENSITY
          13            NUMBER of RAINFALL Events per Year
          14            Avg. SNOWMELT Event DURATION
          15            Avg. SNOWMELT Event INTENSITY
          16            NUMBER of SNOWMELT Events per Year
          17            Average ANNUAL Precipitation
          18            10-yr Return Period, 24-hr RAINFALL
   Enter the NUMBER for the PARAMETER to be CHANGED :? 12
   AVERAGE EVENT INTENSITY (RAINFALL) IS PRESENTLY- .735
   ENTER YOUR NEW VALUE-? .755
```

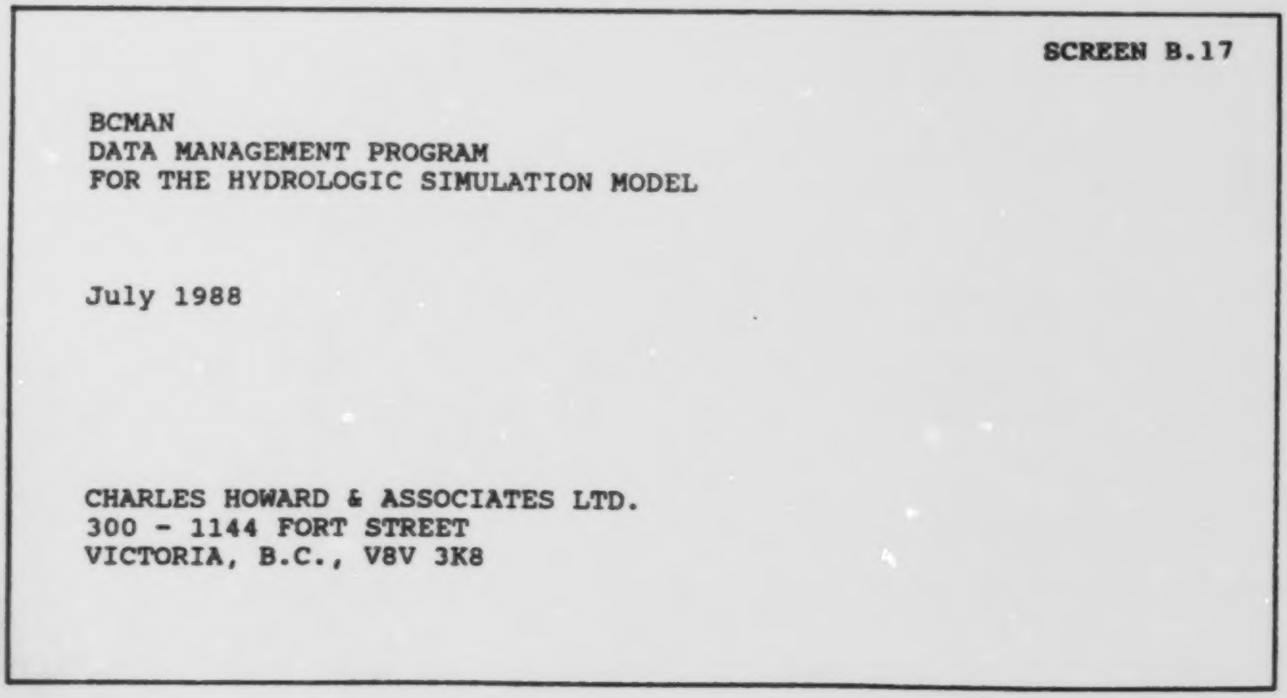


SCREEN B.15

```
                        Save Data Set


Enter the disc drive to be used (A - Z or <CR> for default)? C




Enter the FILENAME to be used - without extension (eg. DEMO)
? COCH
```



```
                                                            SCREEN B.16


FLOOD FREQUENCY CURVE - COCHRANE

DISCHARGE  INTENSITY  TIME(HR)       RETURN PERIOD IN YEARS
  (cms)      (mm/hr) CONCENTRATION   RAINFALL  SNOWMELT  COMBINED
    3.06       2.76           1.8           1         0         1
    3.63       3.27           1.7           2         0         2
    4.20       3.78           1.6           4         0         4
    4.77       4.29           1.5           8         0         8
    5.33       4.80           1.4          14         0        14
    5.90       5.31           1.4          28         0        28
    6.47       5.82           1.3          54         0        54
    7.04       6.33           1.3         104         0       104
    7.60       6.84           1.2         204         0       204
    8.17       7.35           1.2         403         0       403
    8.74       7.86           1.2         810         0       810
    9.30       8.37           1.1        1694         0      1694
    9.87       8.88           1.1        3868         0      3868
   10.44       9.40           1.1       11391         0     11391

              Hit  RETURN  to continue...
```



```
                                                          SCREEN B.17

    BCMAN
    DATA MANAGEMENT PROGRAM
    FOR THE HYDROLOGIC SIMULATION MODEL


    July 1988




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```
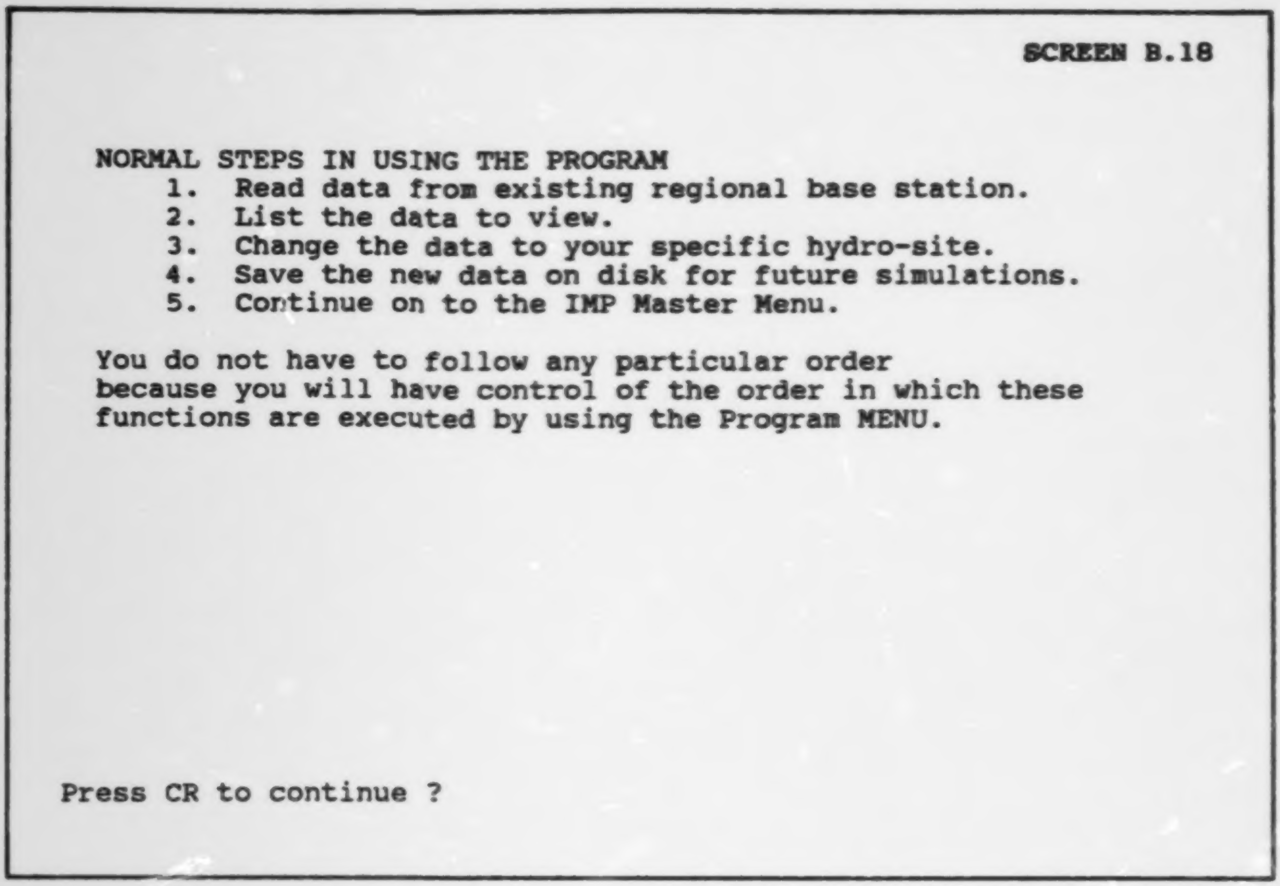
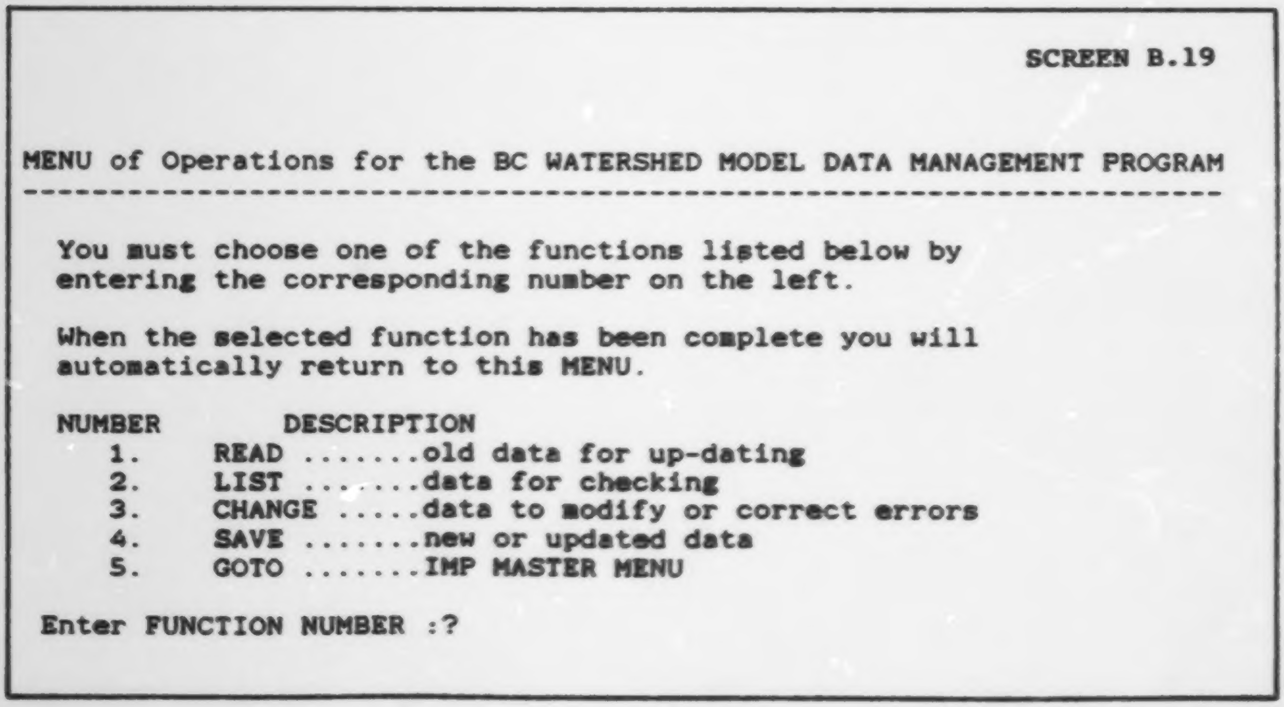
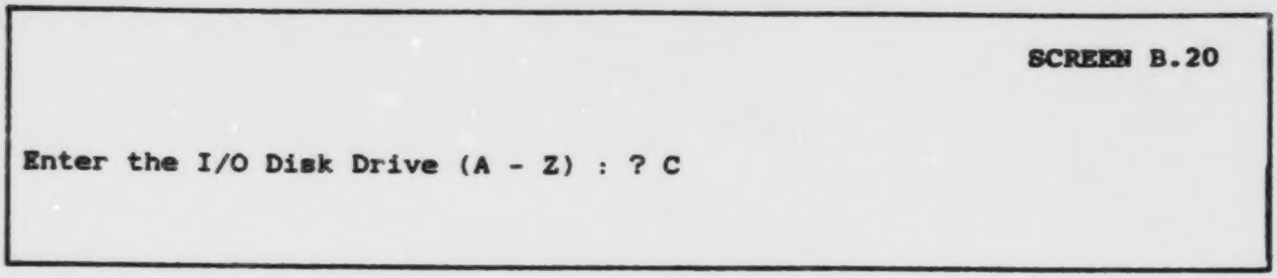



```
                                                    SCREEN B.18


    NORMAL STEPS IN USING THE PROGRAM
        1.  Read data from existing regional base station.
        2.  List the data to view.
        3.  Change the data to your specific hydro-site.
        4.  Save the new data on disk for future simulations.
        5.  Continue on to the IMP Master Menu.

    You do not have to follow any particular order
    because you will have control of the order in which these
    functions are executed by using the Program MENU.











  Press CR to continue ?
```

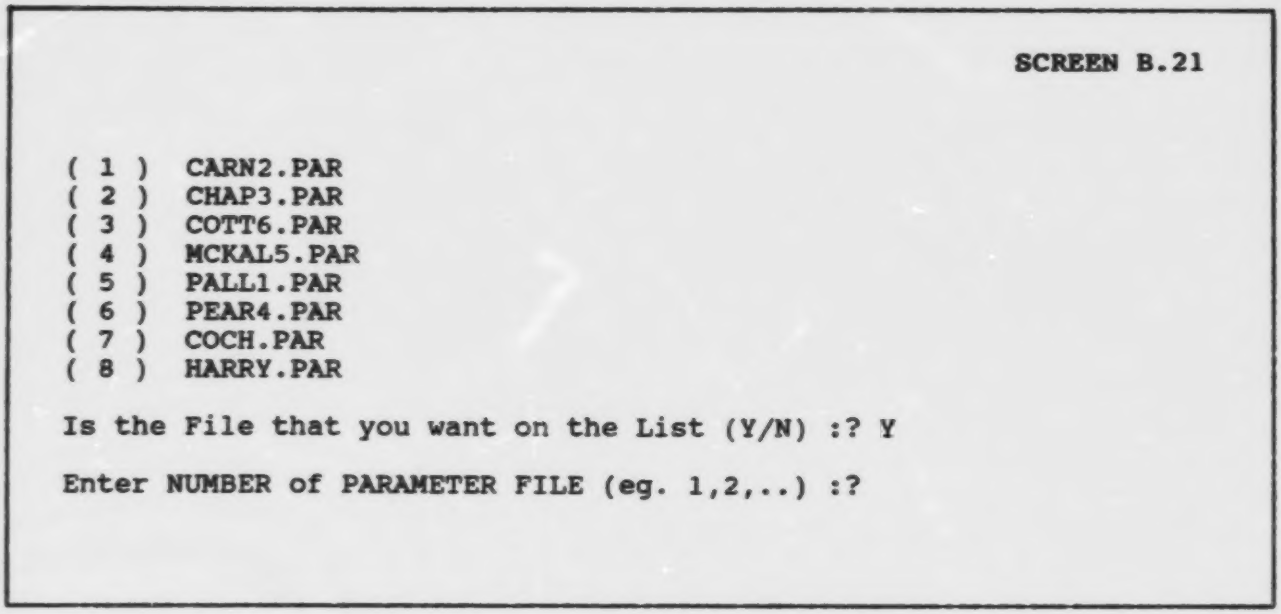


```
                                                    SCREEN B.19


MENU of Operations for the BC WATERSHED MODEL DATA MANAGEMENT PROGRAM
---------------------------------------------------------------------

  You must choose one of the functions listed below by
  entering the corresponding number on the left.

  When the selected function has been complete you will
  automatically return to this MENU.

  NUMBER       DESCRIPTION
     1.     READ .......old data for up-dating
     2.     LIST .......data for checking
     3.     CHANGE .....data to modify or correct errors
     4.     SAVE .......new or updated data
     5.     GOTO .......IMP MASTER MENU

 Enter FUNCTION NUMBER :?
```



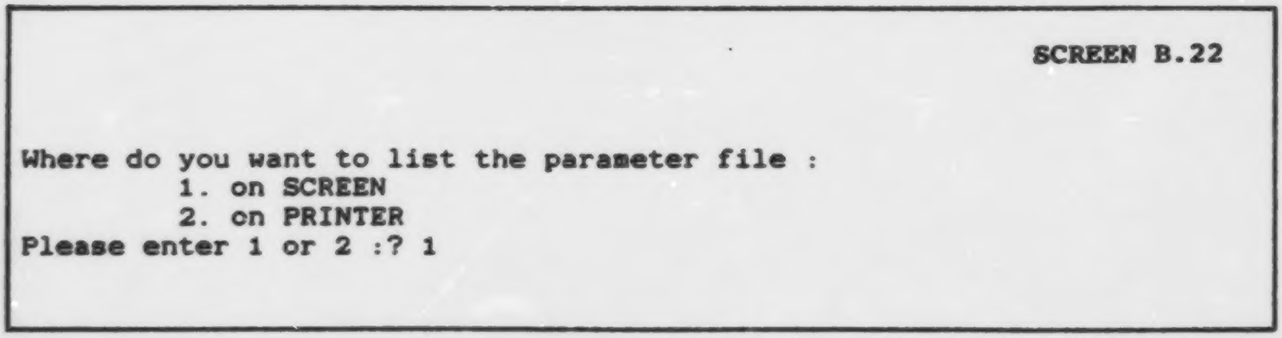
SCREEN B.20

```
Enter the I/O Disk Drive (A - Z) : ? C
```



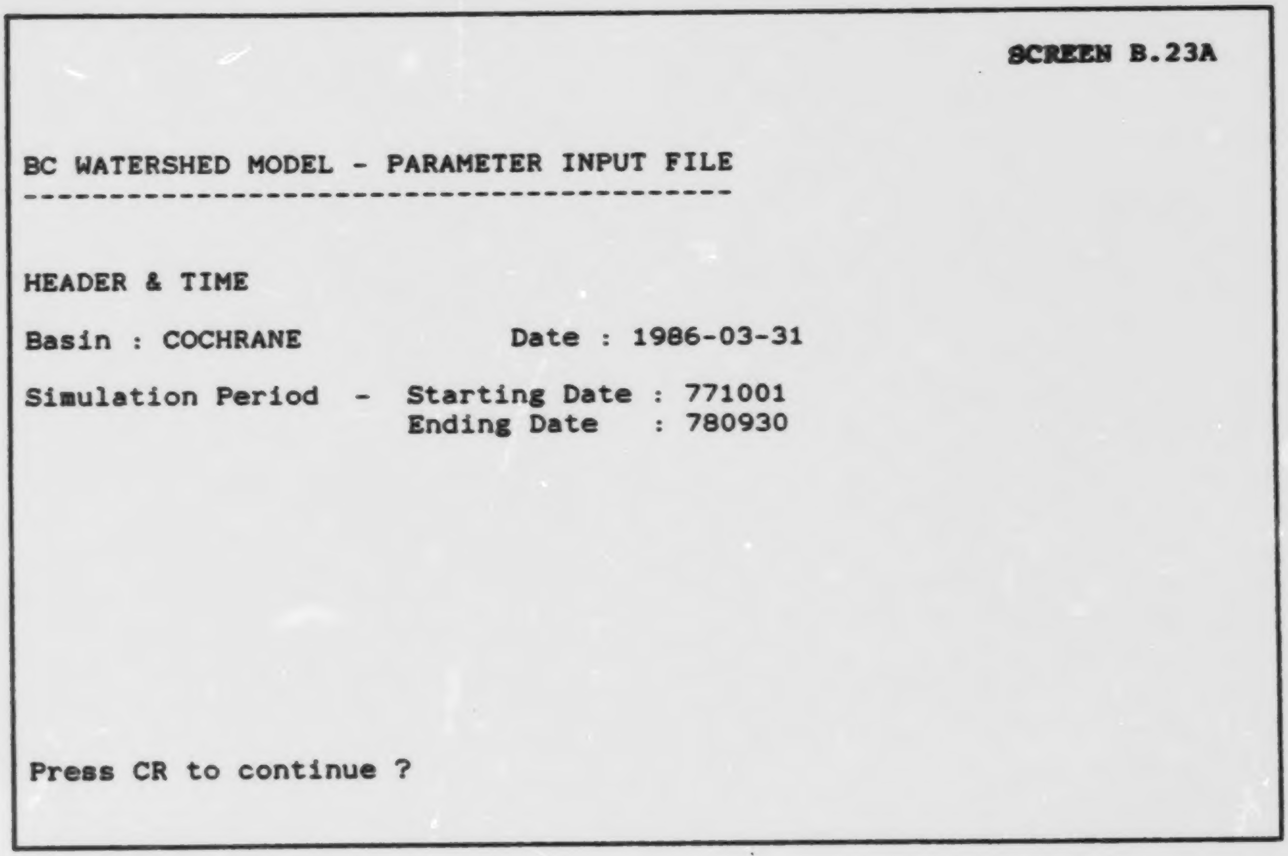
SCREEN B.21

```
  ( 1 )  CARN2.PAR
  ( 2 )  CHAP3.PAR
  ( 3 )  COTT6.PAR
  ( 4 )  MCKAL5.PAR
  ( 5 )  PALL1.PAR
  ( 6 )  PEAR4.PAR
  ( 7 )  COCH.PAR
  ( 8 )  HARRY.PAR

  Is the File that you want on the List (Y/N) :? Y

  Enter NUMBER of PARAMETER FILE (eg. 1,2,..) :?
```

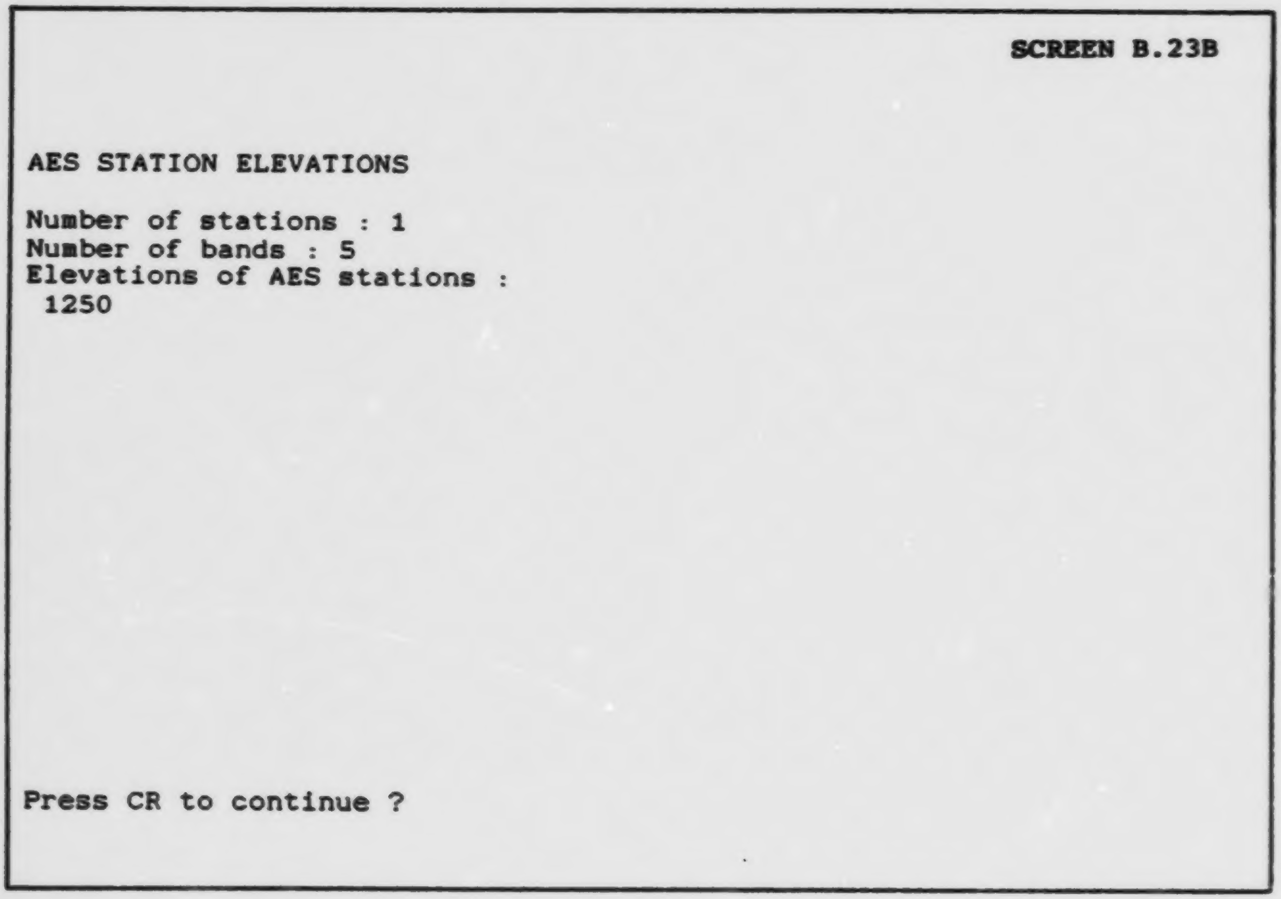


SCREEN B.22

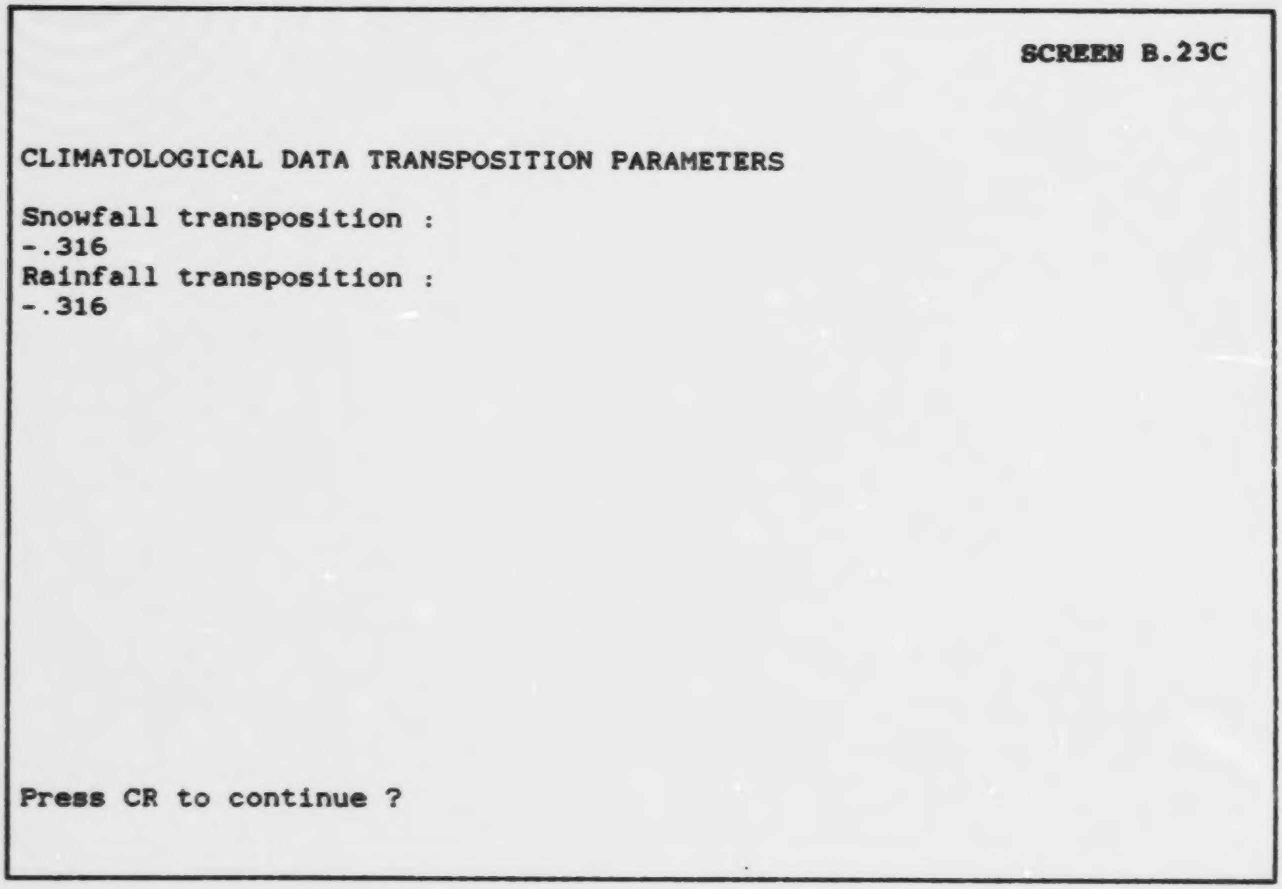
```
Where do you want to list the parameter file :
         1. on SCREEN
         2. on PRINTER
Please enter 1 or 2 :? 1
```



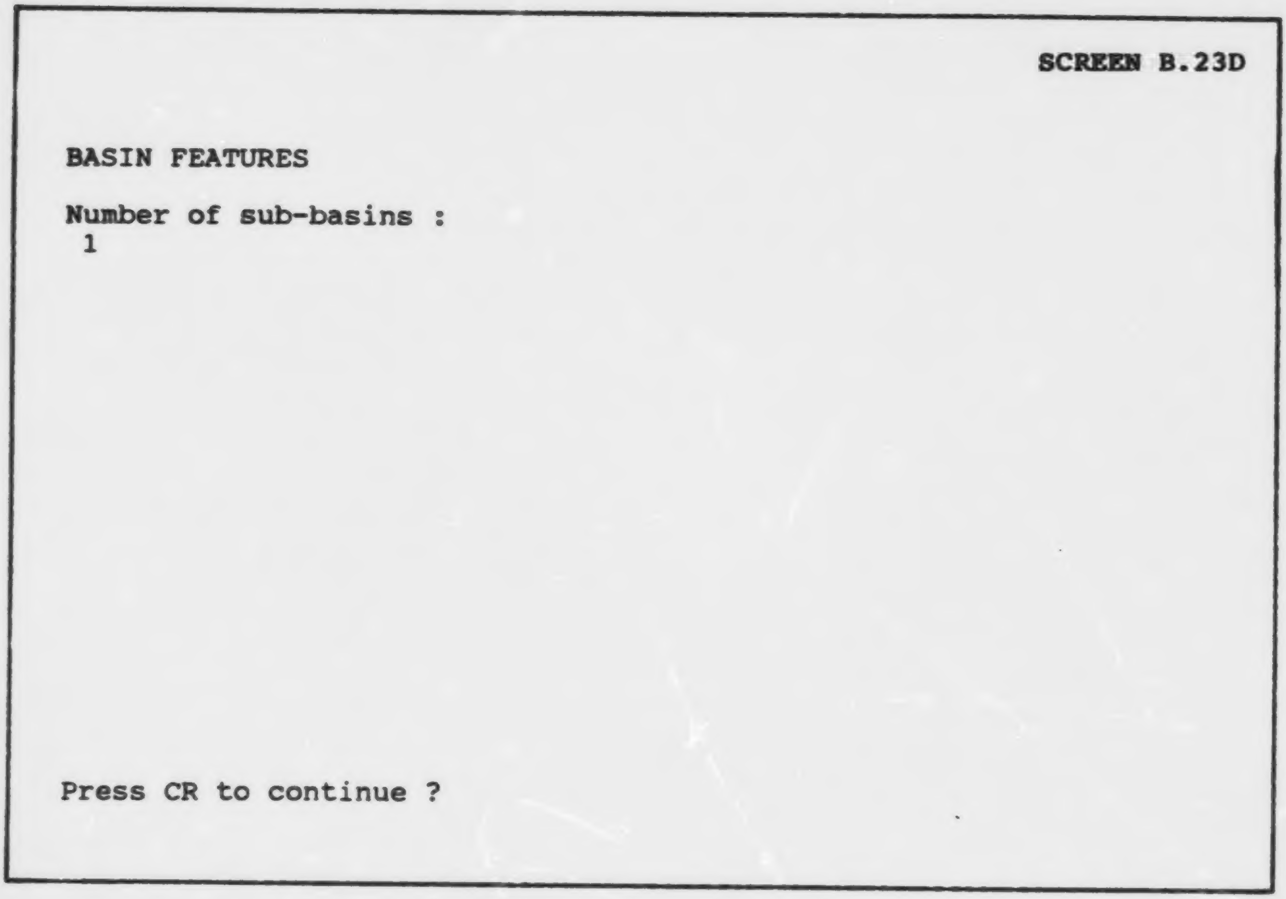
```
                                                          SCREEN B.23A


BC WATERSHED MODEL - PARAMETER INPUT FILE
-----------------------------------------


HEADER & TIME

Basin : COCHRANE              Date : 1986-03-31

Simulation Period  -  Starting Date : 771001
                      Ending Date   : 780930









Press CR to continue ?
```



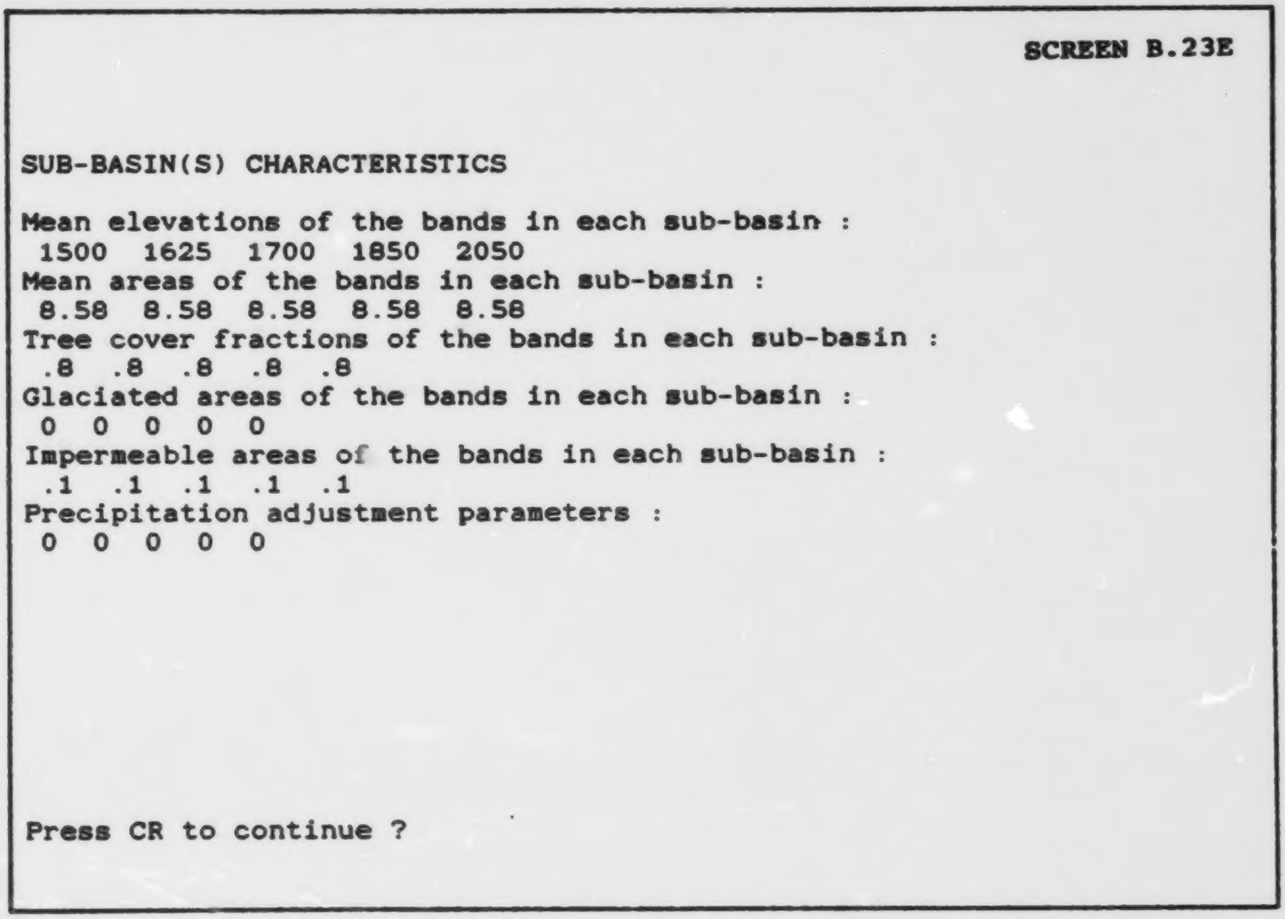
```
                                                        SCREEN B.23B


AES STATION ELEVATIONS

Number of stations : 1
Number of bands : 5
Elevations of AES stations :
 1250















Press CR to continue ?
```



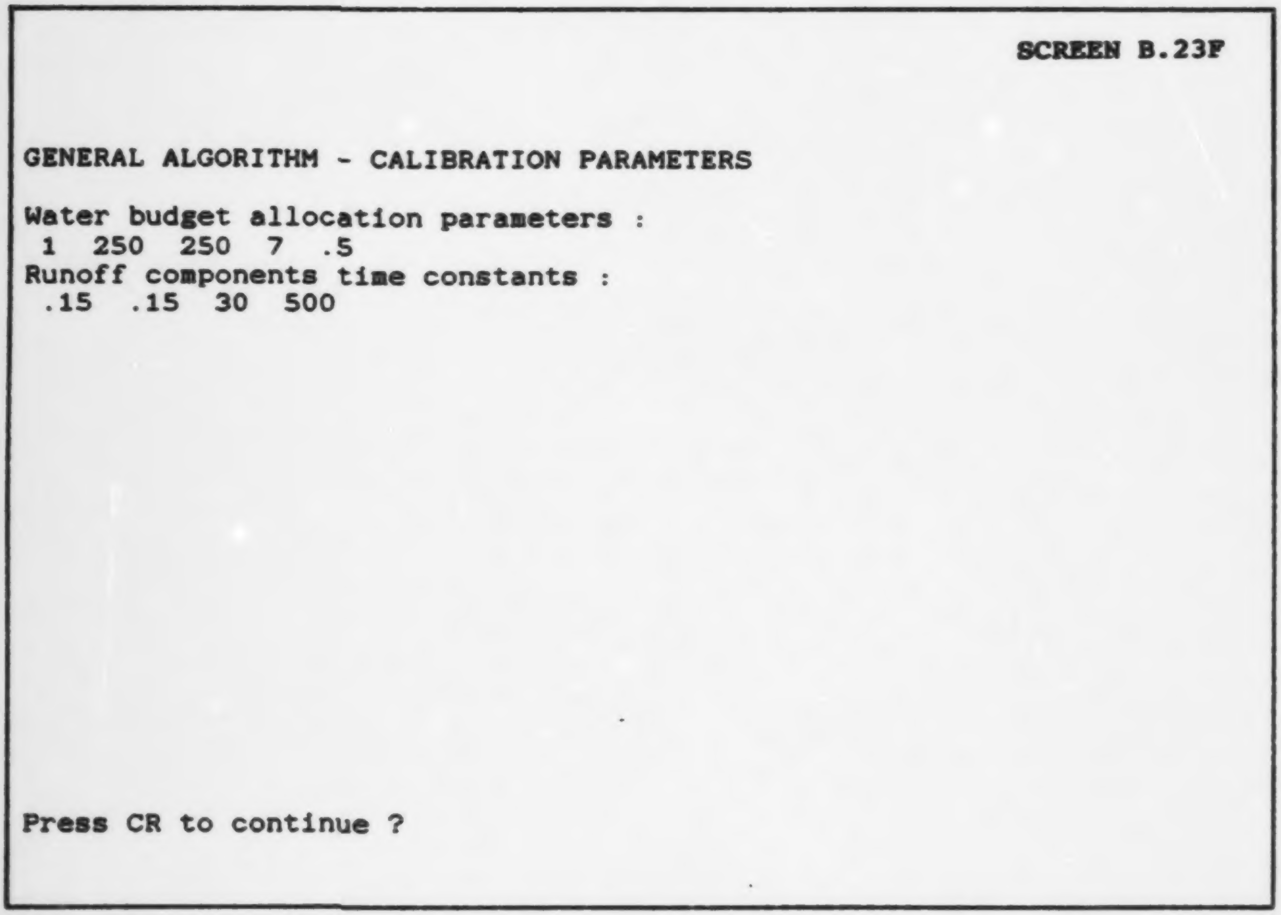
```
                                                    SCREEN B.23C


CLIMATOLOGICAL DATA TRANSPOSITION PARAMETERS

Snowfall transposition :
-.316
Rainfall transposition :
-.316











Press CR to continue ?
```



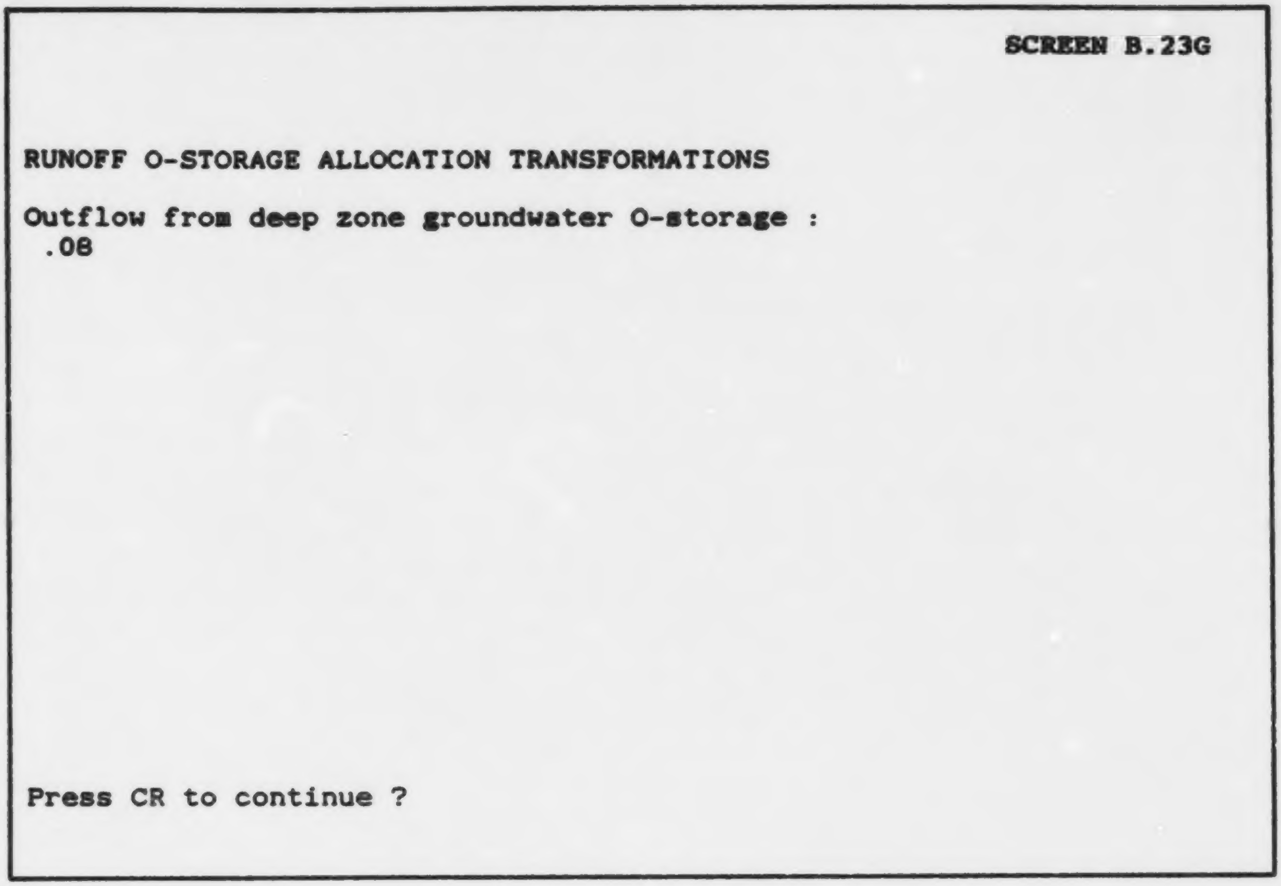
```
                                                    SCREEN B.23D

  BASIN FEATURES

  Number of sub-basins :
   1










  Press CR to continue ?
```



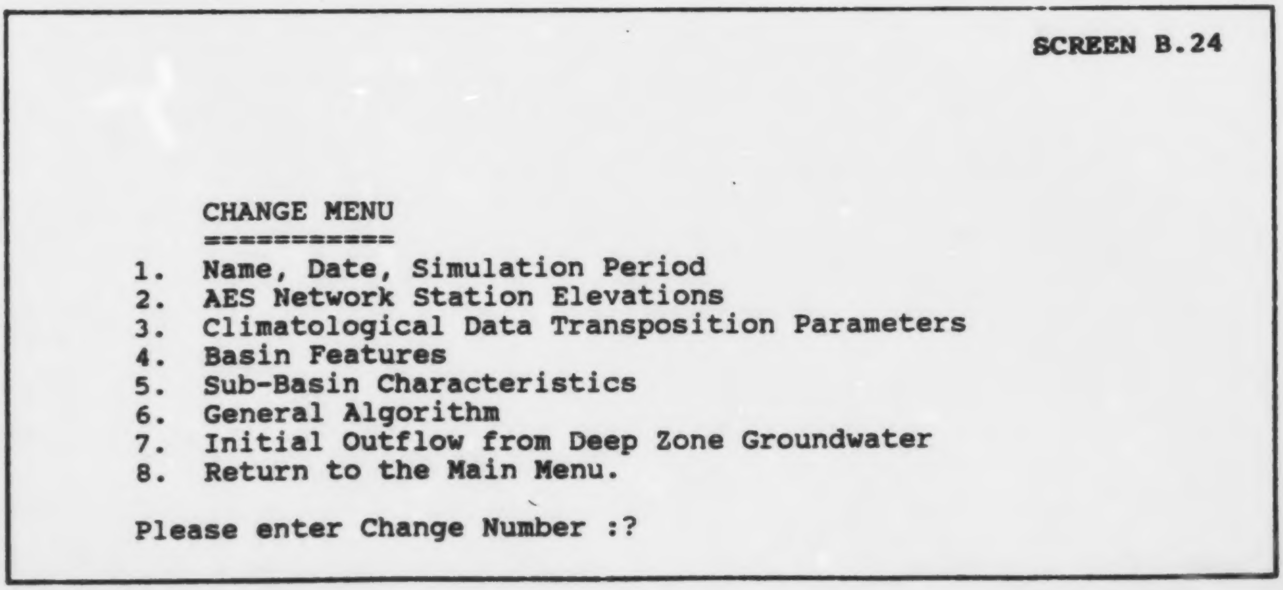
```
                                                    SCREEN B.23E


SUB-BASIN(S) CHARACTERISTICS

Mean elevations of the bands in each sub-basin :
 1500  1625  1700  1850  2050
Mean areas of the bands in each sub-basin :
 8.58  8.58  8.58  8.58  8.58
Tree cover fractions of the bands in each sub-basin :
  .8   .8   .8   .8   .8
Glaciated areas of the bands in each sub-basin :
 0  0  0  0  0
Impermeable areas of the bands in each sub-basin :
  .1   .1   .1   .1   .1
Precipitation adjustment parameters :
 0  0  0  0  0







Press CR to continue ?
```



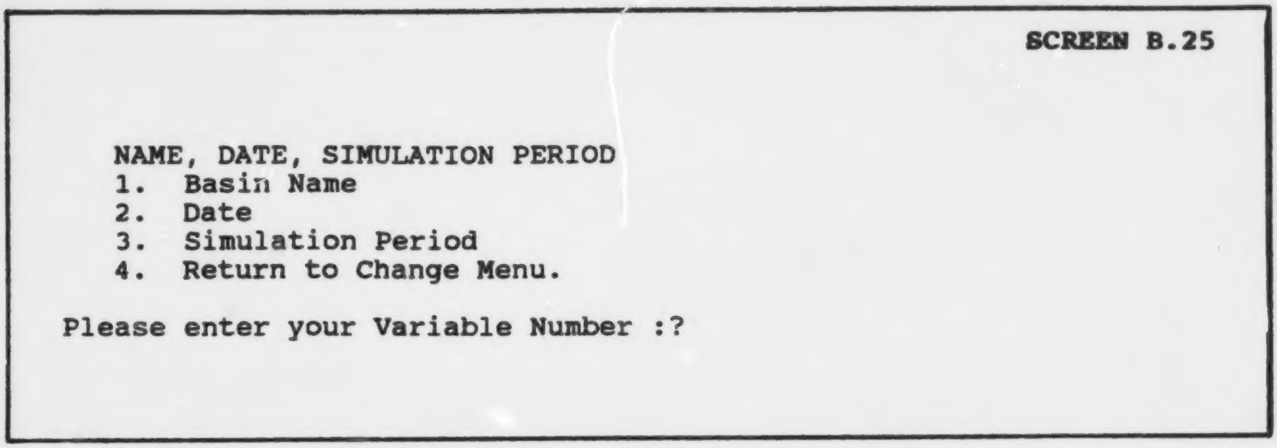
```
                                                            SCREEN B.23F


GENERAL ALGORITHM - CALIBRATION PARAMETERS

Water budget allocation parameters :
 1  250  250  7  .5
Runoff components time constants :
 .15  .15  30  500










Press CR to continue ?
```



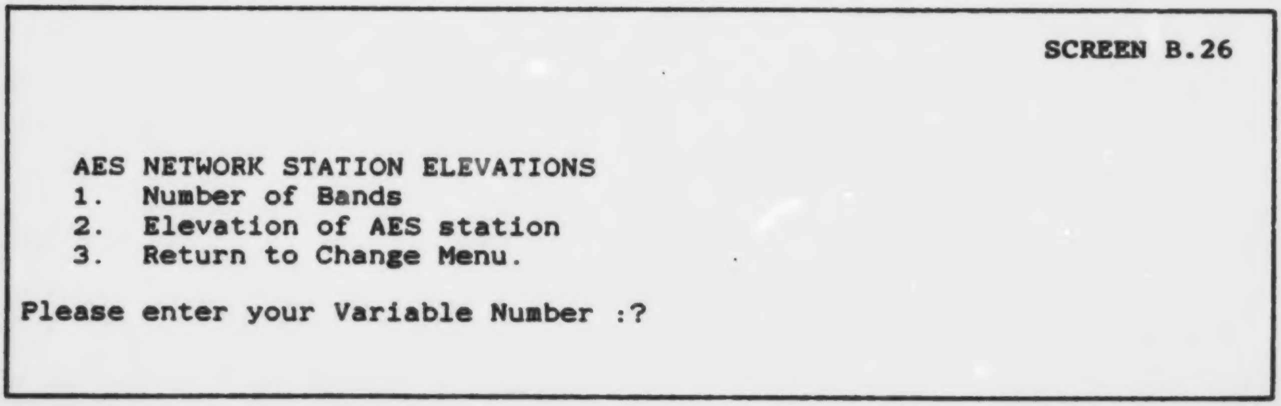
```
                                                    SCREEN B.23G


RUNOFF O-STORAGE ALLOCATION TRANSFORMATIONS

Outflow from deep zone groundwater O-storage :
 .08












Press CR to continue ?
```



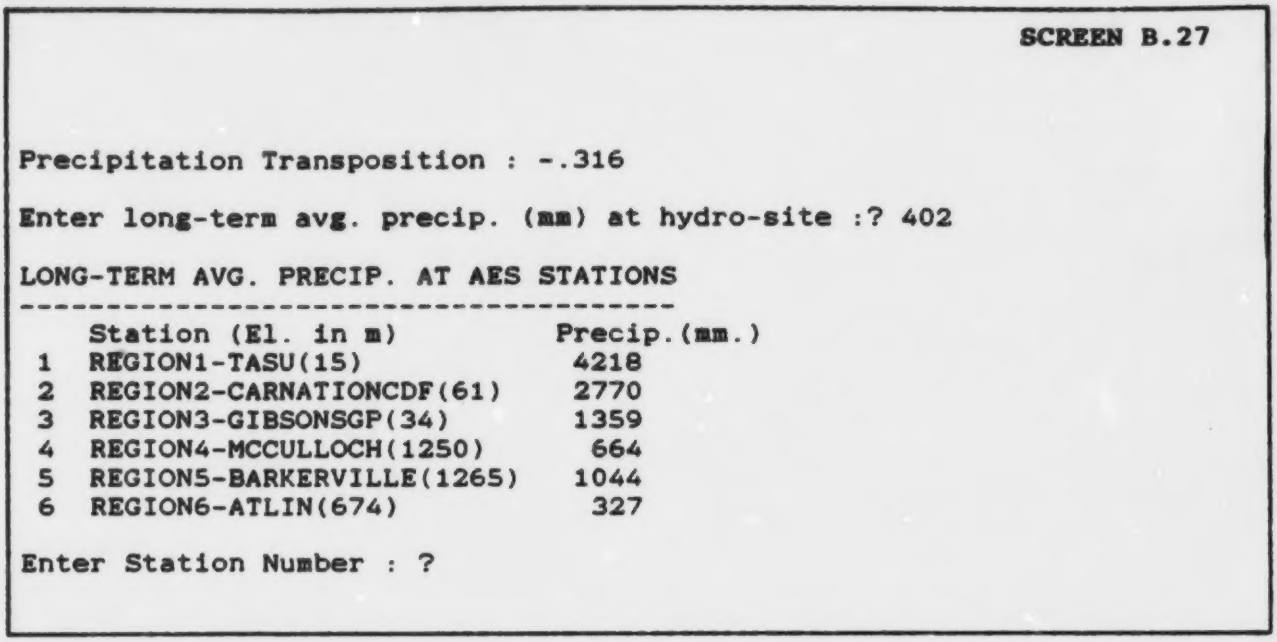
```
                                                         SCREEN B.24




          CHANGE MENU
          ===========
      1.  Name, Date, Simulation Period
      2.  AES Network Station Elevations
      3.  Climatological Data Transposition Parameters
      4.  Basin Features
      5.  Sub-Basin Characteristics
      6.  General Algorithm
      7.  Initial Outflow from Deep Zone Groundwater
      8.  Return to the Main Menu.

      Please enter Change Number :?
```



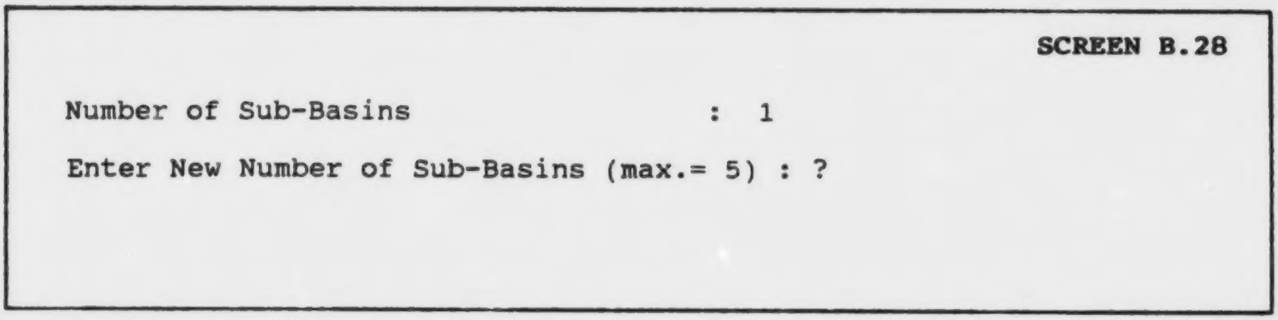
```
                                                        SCREEN B.25


     NAME, DATE, SIMULATION PERIOD
     1.  Basin Name
     2.  Date
     3.  Simulation Period
     4.  Return to Change Menu.

  Please enter your Variable Number :?
```



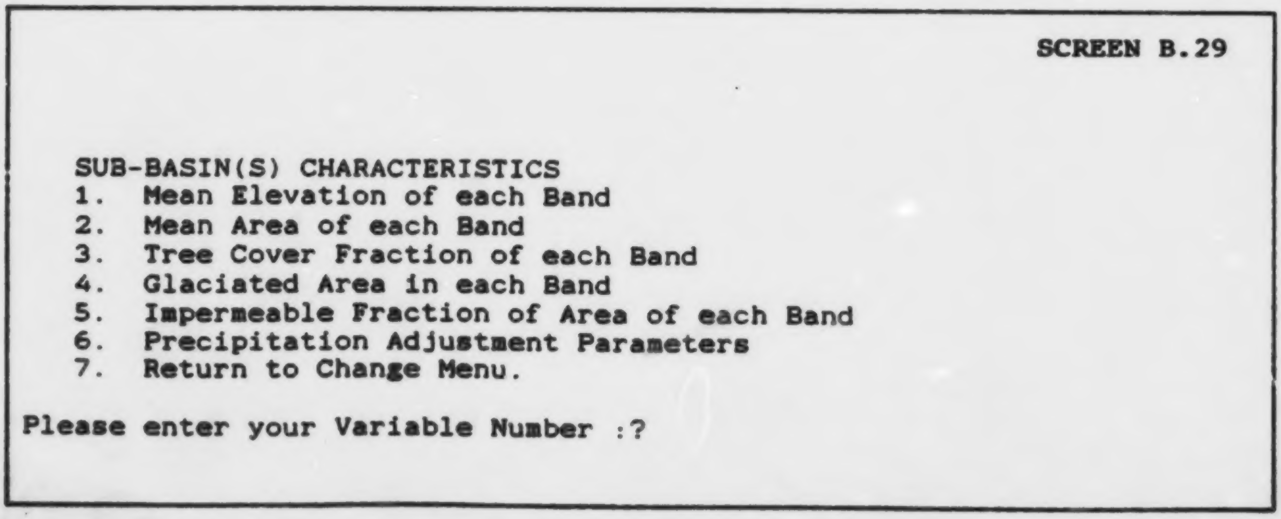
```
                                                        SCREEN B.26


   AES NETWORK STATION ELEVATIONS
   1.  Number of Bands
   2.  Elevation of AES station
   3.  Return to Change Menu.

Please enter your Variable Number :?
```



```
                                                     SCREEN B.27



Precipitation Transposition : -.316

Enter long-term avg. precip. (mm) at hydro-site :? 402

LONG-TERM AVG. PRECIP. AT AES STATIONS
--------------------------------------
    Station (El. in m)          Precip.(mm.)
 1  REGION1-TASU(15)              4218
 2  REGION2-CARNATIONCDF(61)      2770
 3  REGION3-GIBSONSGP(34)         1359
 4  REGION4-MCCULLOCH(1250)        664
 5  REGION5-BARKERVILLE(1265)     1044
 6  REGION6-ATLIN(674)             327

Enter Station Number : ?
```



```
                                                     SCREEN B.28

   Number of Sub-Basins                     :  1

   Enter New Number of Sub-Basins (max.= 5) : ?
```



```
                                                     SCREEN B.29



   SUB-BASIN(S) CHARACTERISTICS
   1.  Mean Elevation of each Band
   2.  Mean Area of each Band
   3.  Tree Cover Fraction of each Band
   4.  Glaciated Area in each Band
   5.  Impermeable Fraction of Area of each Band
   6.  Precipitation Adjustment Parameters
   7.  Return to Change Menu.

Please enter your Variable Number :?
```

SCREEN B.30

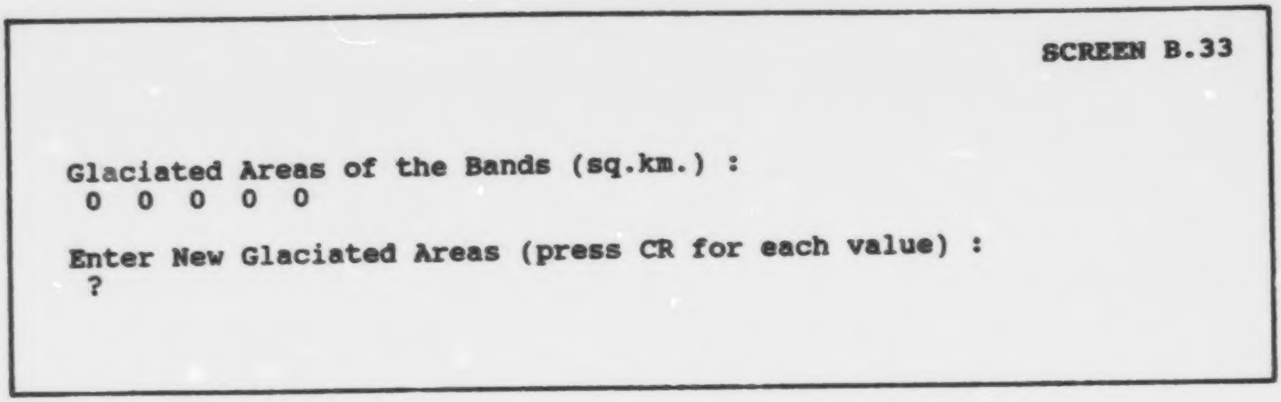
```
Mean Elevations of the Bands (meters) :
 1500  1625  1700  1850  2050

Enter New Elevations (press CR for each value) :
 ?
```

SCREEN B.31

```
Mean Area of the Bands (sq.km.) :
 8.58  8.58  8.58  8.58  8.58

Enter New Areas (press CR for each value) :
 ?
```

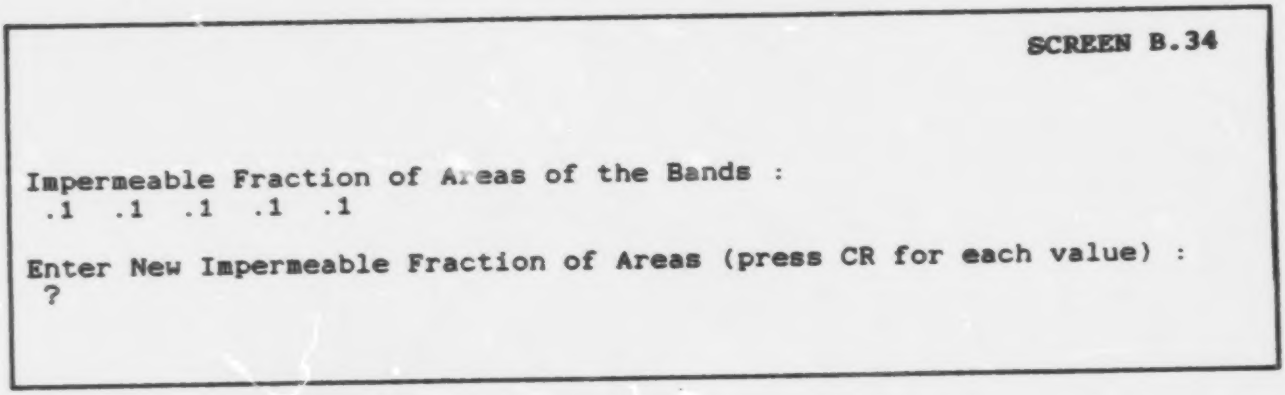
SCREEN B.32

```
Tree Cover Fraction of the Bands :
 .8  .8  .8  .8  .8

Enter New Tree Cover Fractions (press CR for each value) :
 ?
```



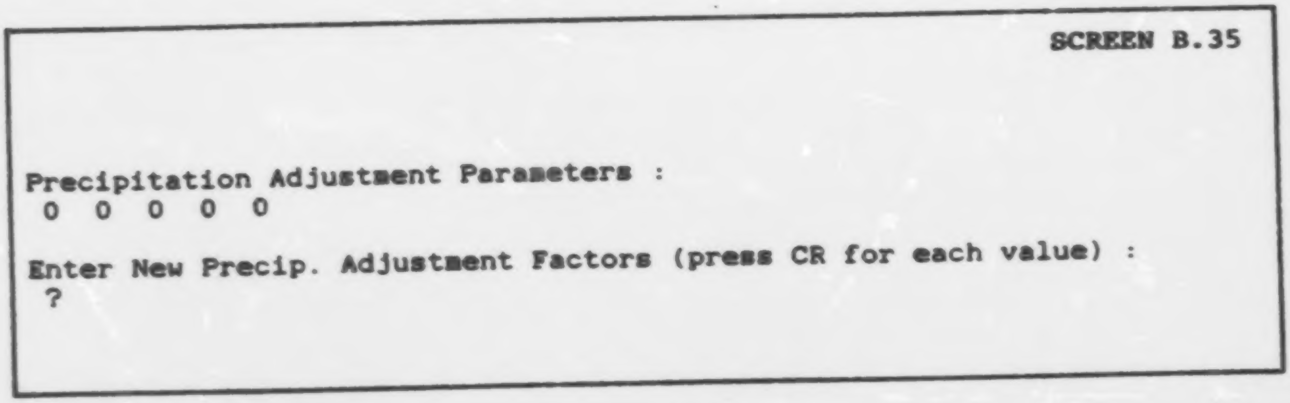
SCREEN B.33

```
Glaciated Areas of the Bands (sq.km.) :
 0  0  0  0  0

Enter New Glaciated Areas (press CR for each value) :
 ?
```



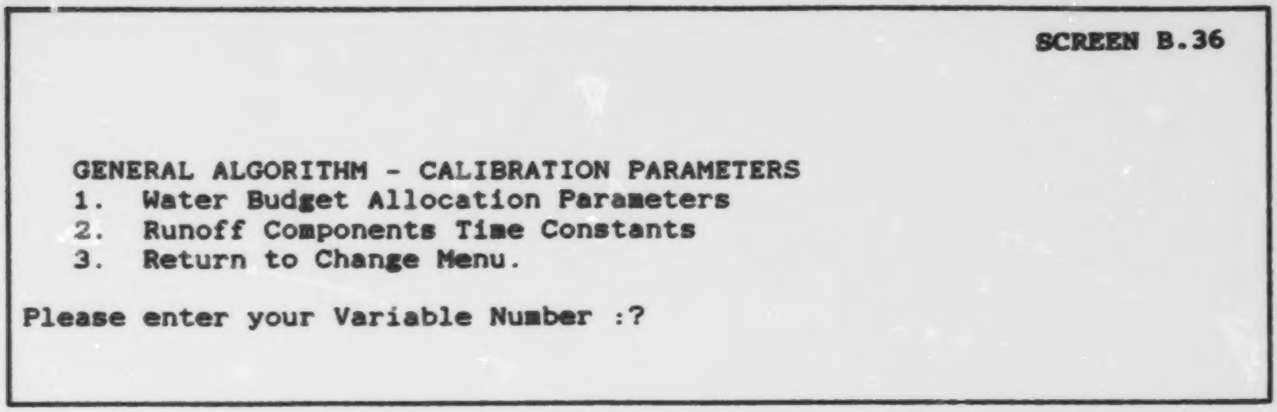
SCREEN B.34

```
Impermeable Fraction of Areas of the Bands :
 .1  .1  .1  .1  .1

Enter New Impermeable Fraction of Areas (press CR for each value) :
 ?
```



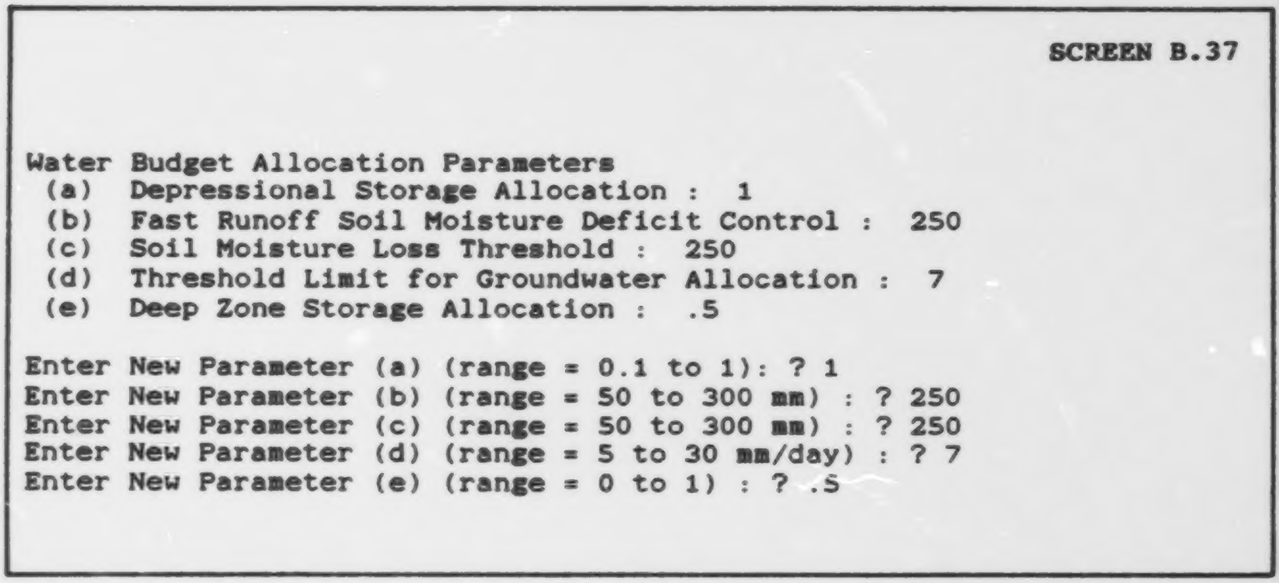
SCREEN B.35

```
Precipitation Adjustment Parameters :
 0  0  0  0  0

Enter New Precip. Adjustment Factors (press CR for each value) :
 ?
```



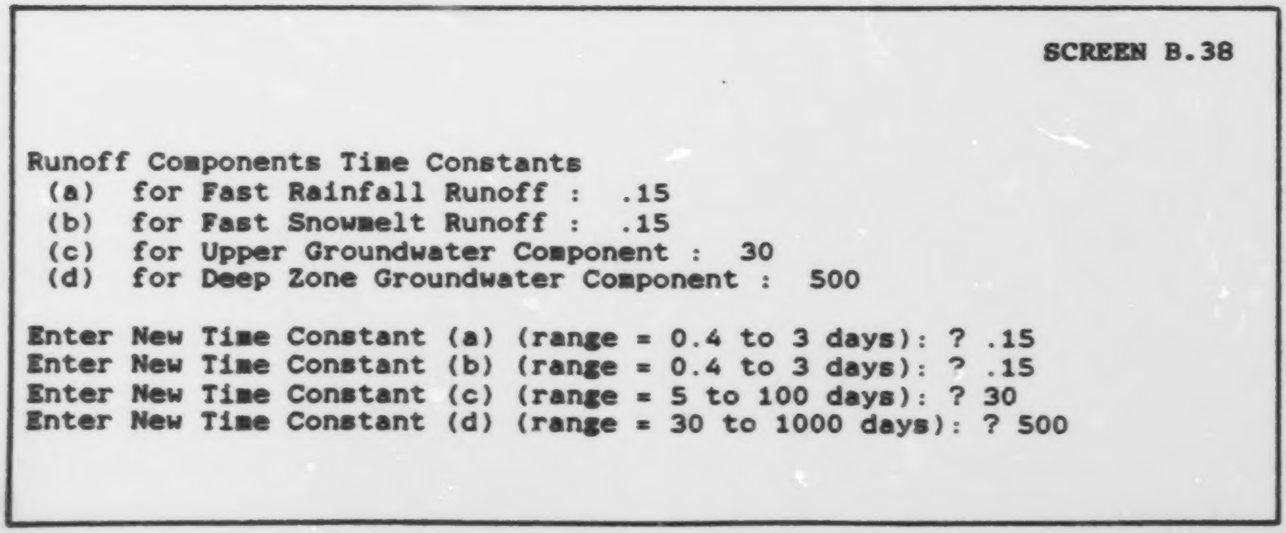
SCREEN B.36

```
   GENERAL ALGORITHM - CALIBRATION PARAMETERS
   1.  Water Budget Allocation Parameters
   2.  Runoff Components Time Constants
   3.  Return to Change Menu.

Please enter your Variable Number :?
```



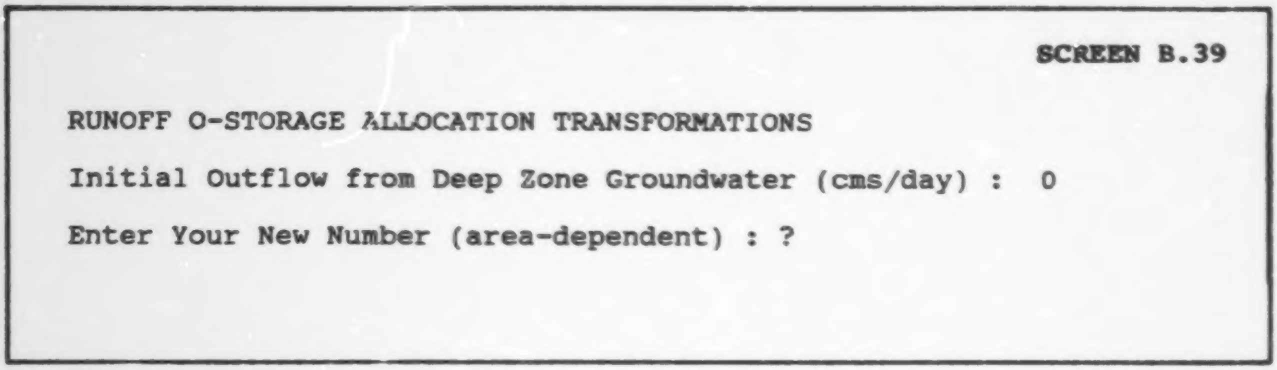
SCREEN B.37

```
Water Budget Allocation Parameters
 (a)  Depressional Storage Allocation :  1
 (b)  Fast Runoff Soil Moisture Deficit Control :  250
 (c)  Soil Moisture Loss Threshold :  250
 (d)  Threshold Limit for Groundwater Allocation :  7
 (e)  Deep Zone Storage Allocation :  .5

Enter New Parameter (a) (range = 0.1 to 1): ? 1
Enter New Parameter (b) (range = 50 to 300 mm) : ? 250
Enter New Parameter (c) (range = 50 to 300 mm) : ? 250
Enter New Parameter (d) (range = 5 to 30 mm/day) : ? 7
Enter New Parameter (e) (range = 0 to 1) : ? .5
```

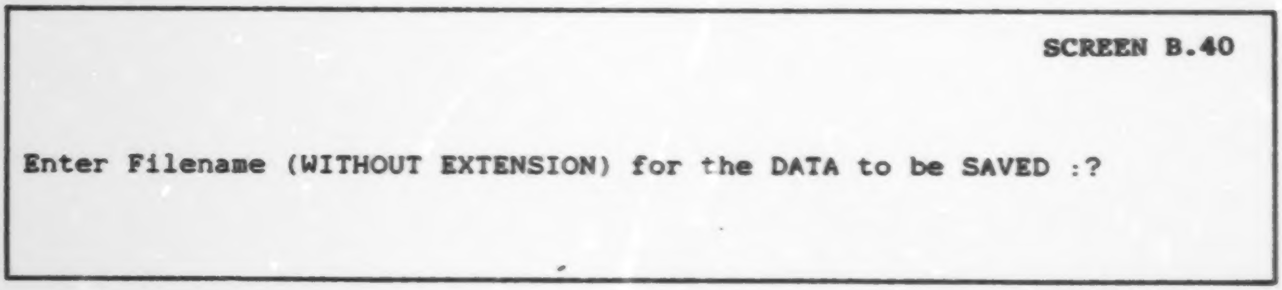


SCREEN B.38

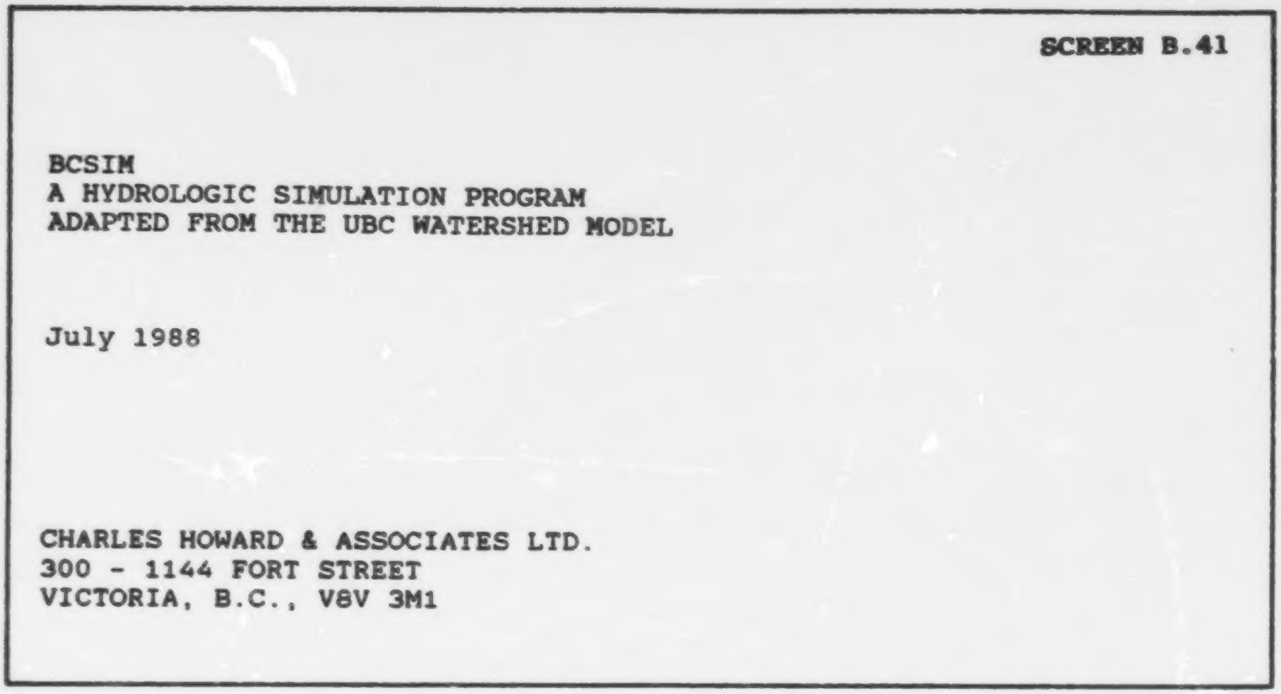
```
Runoff Components Time Constants
 (a)  for Fast Rainfall Runoff :  .15
 (b)  for Fast Snowmelt Runoff :  .15
 (c)  for Upper Groundwater Component :  30
 (d)  for Deep Zone Groundwater Component :  500

Enter New Time Constant (a) (range = 0.4 to 3 days): ? .15
Enter New Time Constant (b) (range = 0.4 to 3 days): ? .15
Enter New Time Constant (c) (range = 5 to 100 days): ? 30
Enter New Time Constant (d) (range = 30 to 1000 days): ? 500
```



```
                                                        SCREEN B.39

   RUNOFF O-STORAGE ALLOCATION TRANSFORMATIONS

   Initial Outflow from Deep Zone Groundwater (cms/day) :  0

   Enter Your New Number (area-dependent) : ?
```

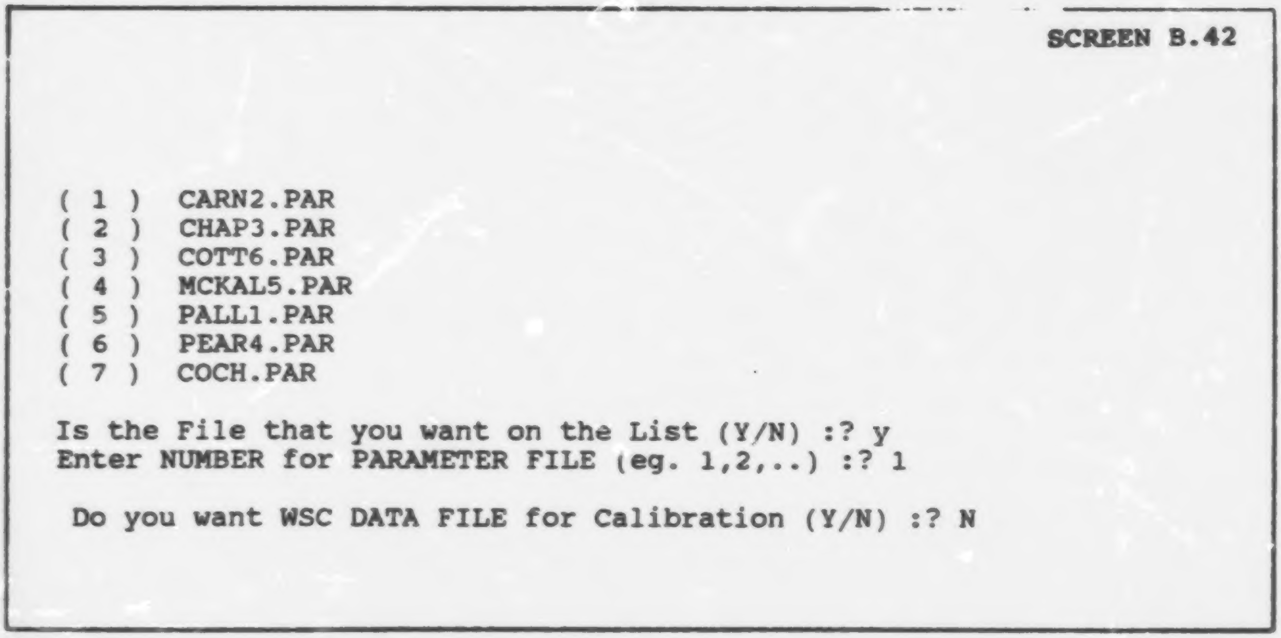


```
                                                        SCREEN B.40

Enter Filename (WITHOUT EXTENSION) for the DATA to be SAVED :?
```



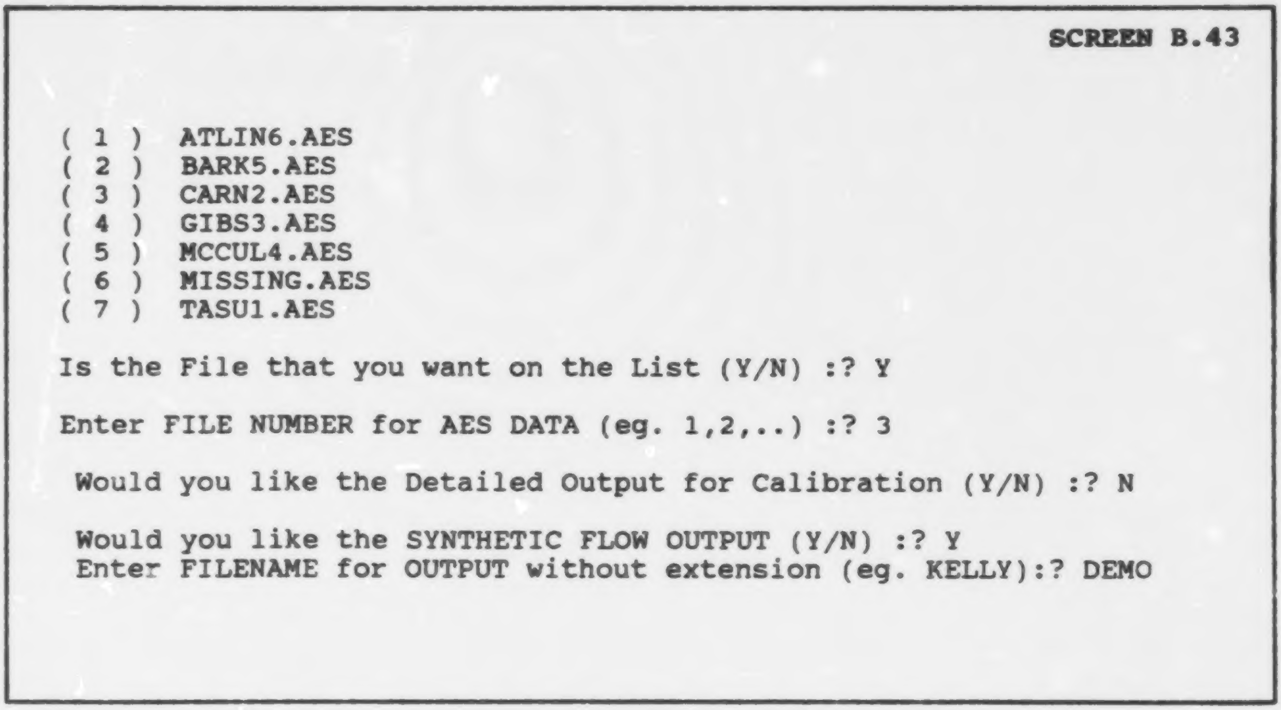
SCREEN B.41

```
BCSIM
A HYDROLOGIC SIMULATION PROGRAM
ADAPTED FROM THE UBC WATERSHED MODEL


July 1988




CHARLES HOWARD & ASSOCIATES LTD.
300 - 1144 FORT STREET
VICTORIA, B.C., V8V 3M1
```



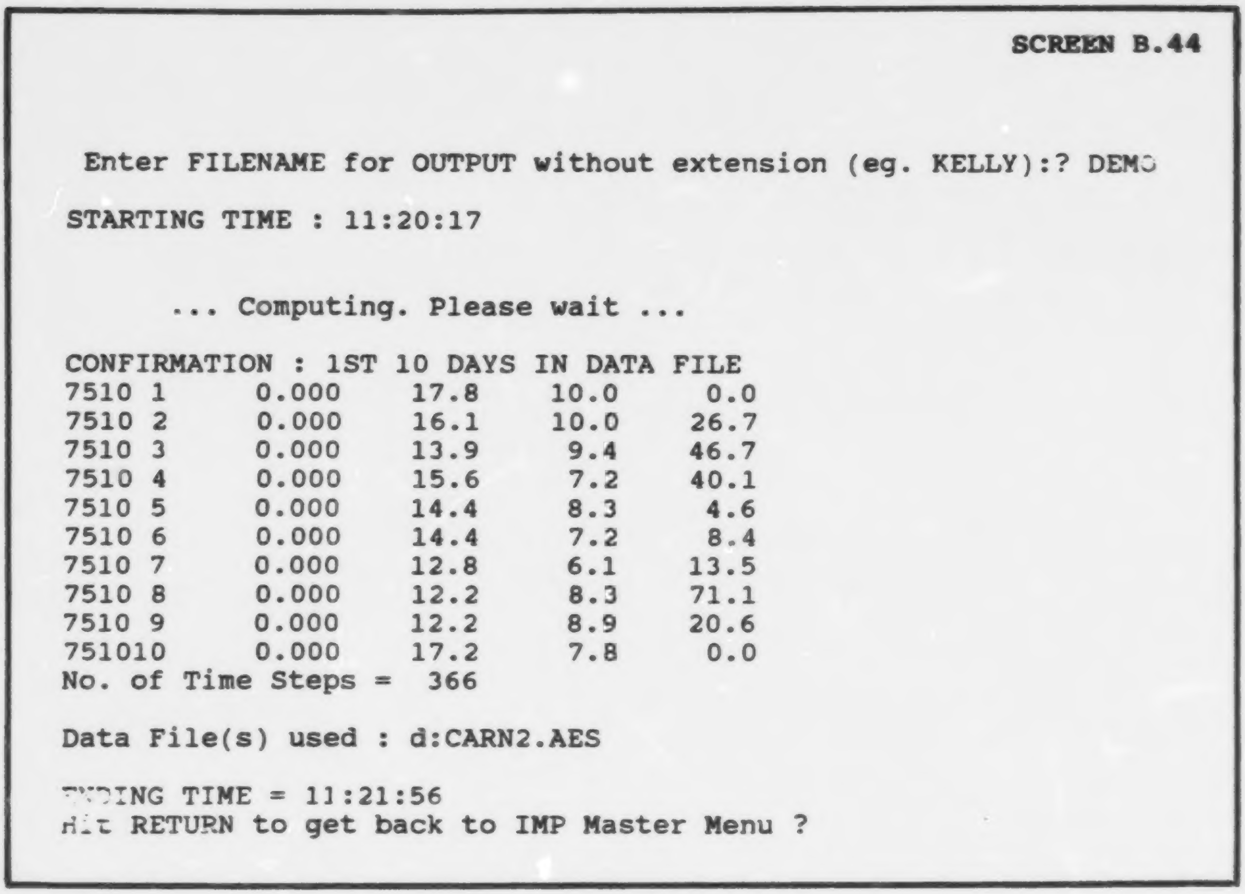
SCREEN B.42

```
( 1 )  CARN2.PAR
( 2 )  CHAP3.PAR
( 3 )  COTT6.PAR
( 4 )  MCKAL5.PAR
( 5 )  PALL1.PAR
( 6 )  PEAR4.PAR
( 7 )  COCH.PAR

Is the File that you want on the List (Y/N) :? y
Enter NUMBER for PARAMETER FILE (eg. 1,2,..) :? 1

 Do you want WSC DATA FILE for Calibration (Y/N) :? N
```



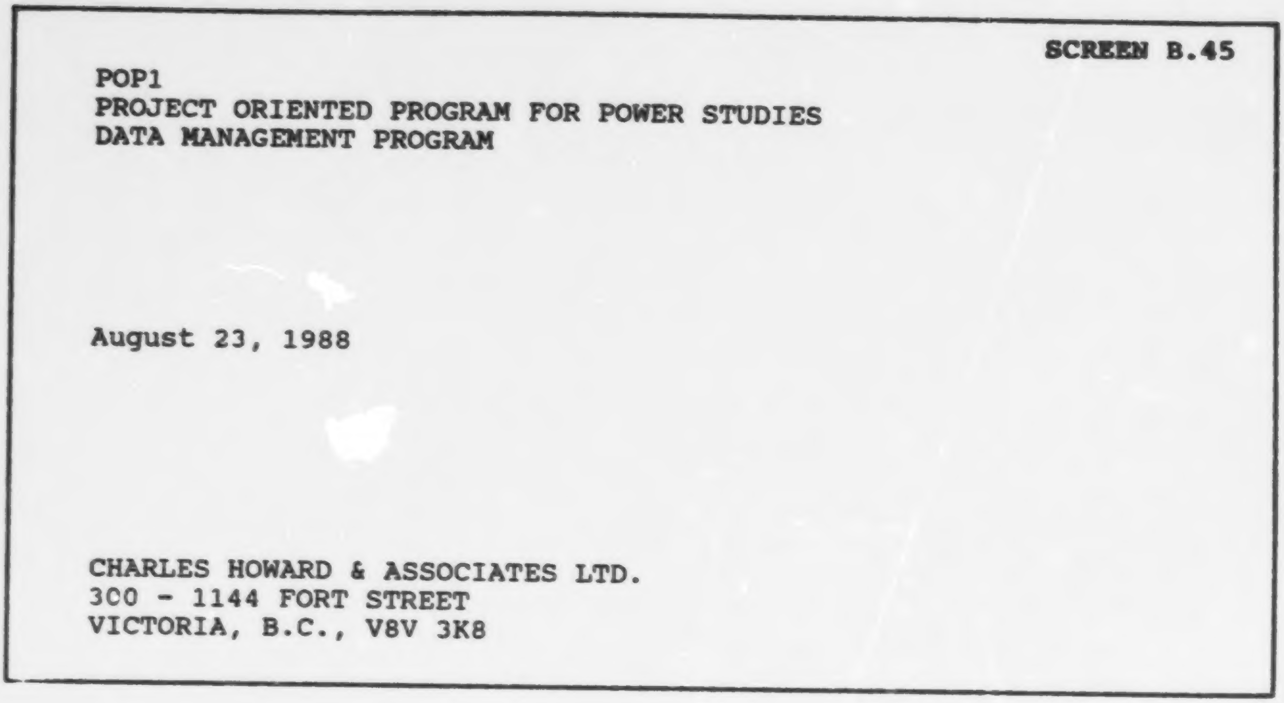
SCREEN B.43

```
( 1 )  ATLIN6.AES
( 2 )  BARK5.AES
( 3 )  CARN2.AES
( 4 )  GIBS3.AES
( 5 )  MCCUL4.AES
( 6 )  MISSING.AES
( 7 )  TASU1.AES

Is the File that you want on the List (Y/N) :? Y

Enter FILE NUMBER for AES DATA (eg. 1,2,..) :? 3

 Would you like the Detailed Output for Calibration (Y/N) :? N

 Would you like the SYNTHETIC FLOW OUTPUT (Y/N) :? Y
 Enter FILENAME for OUTPUT without extension (eg. KELLY):? DEMO
```



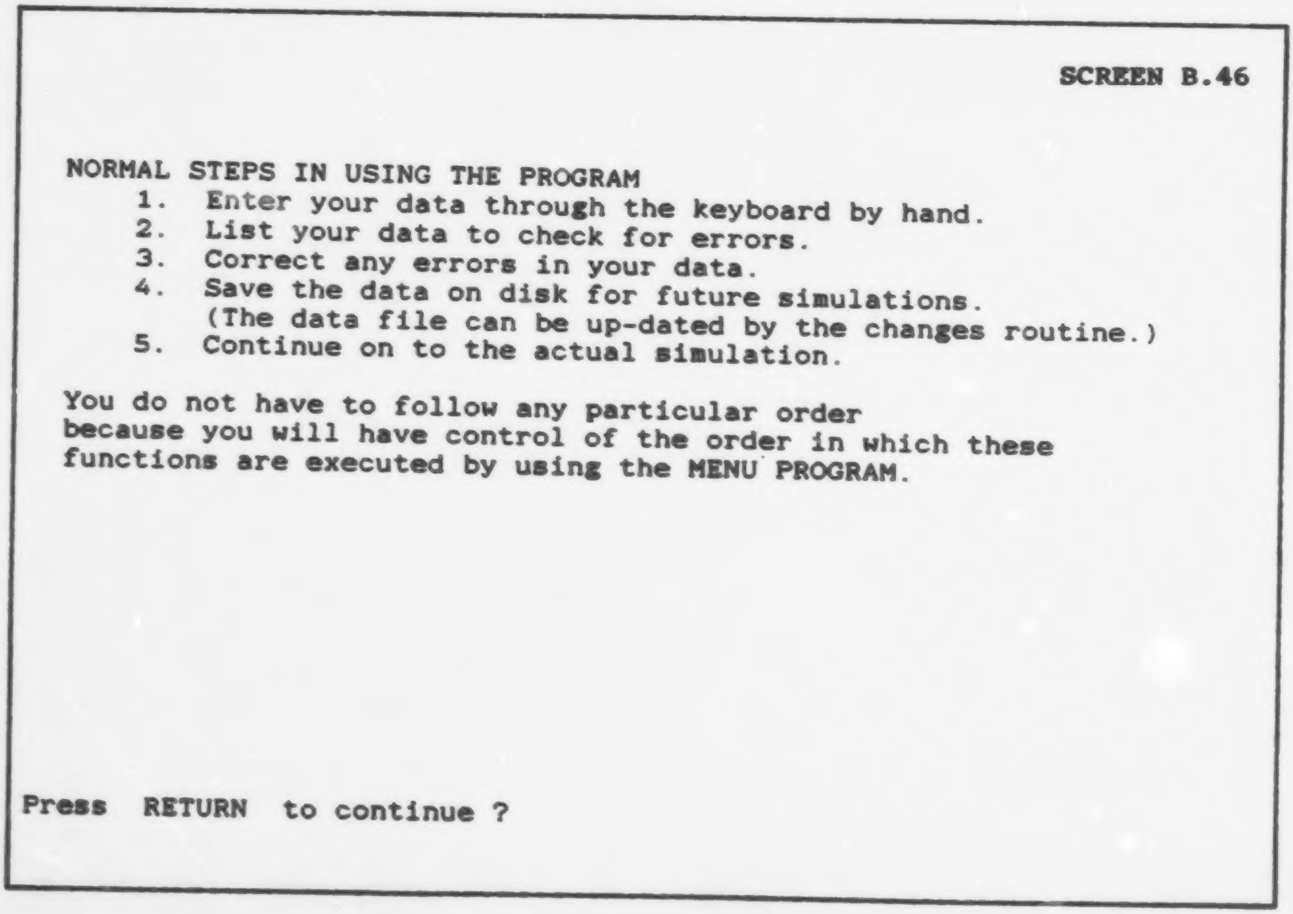
SCREEN B.44

```
 Enter FILENAME for OUTPUT without extension (eg. KELLY):? DEMO

STARTING TIME : 11:20:17


      ... Computing. Please wait ...

CONFIRMATION : 1ST 10 DAYS IN DATA FILE
7510 1      0.000    17.8     10.0      0.0
7510 2      0.000    16.1     10.0     26.7
7510 3      0.000    13.9      9.4     46.7
7510 4      0.000    15.6      7.2     40.1
7510 5      0.000    14.4      8.3      4.6
7510 6      0.000    14.4      7.2      8.4
7510 7      0.000    12.8      6.1     13.5
7510 8      0.000    12.2      8.3     71.1
7510 9      0.000    12.2      8.9     20.6
751010      0.000    17.2      7.8      0.0
No. of Time Steps =  366

Data File(s) used : d:CARN2.AES

ENDING TIME = 11:21:56
Hit RETURN to get back to IMP Master Menu ?
```



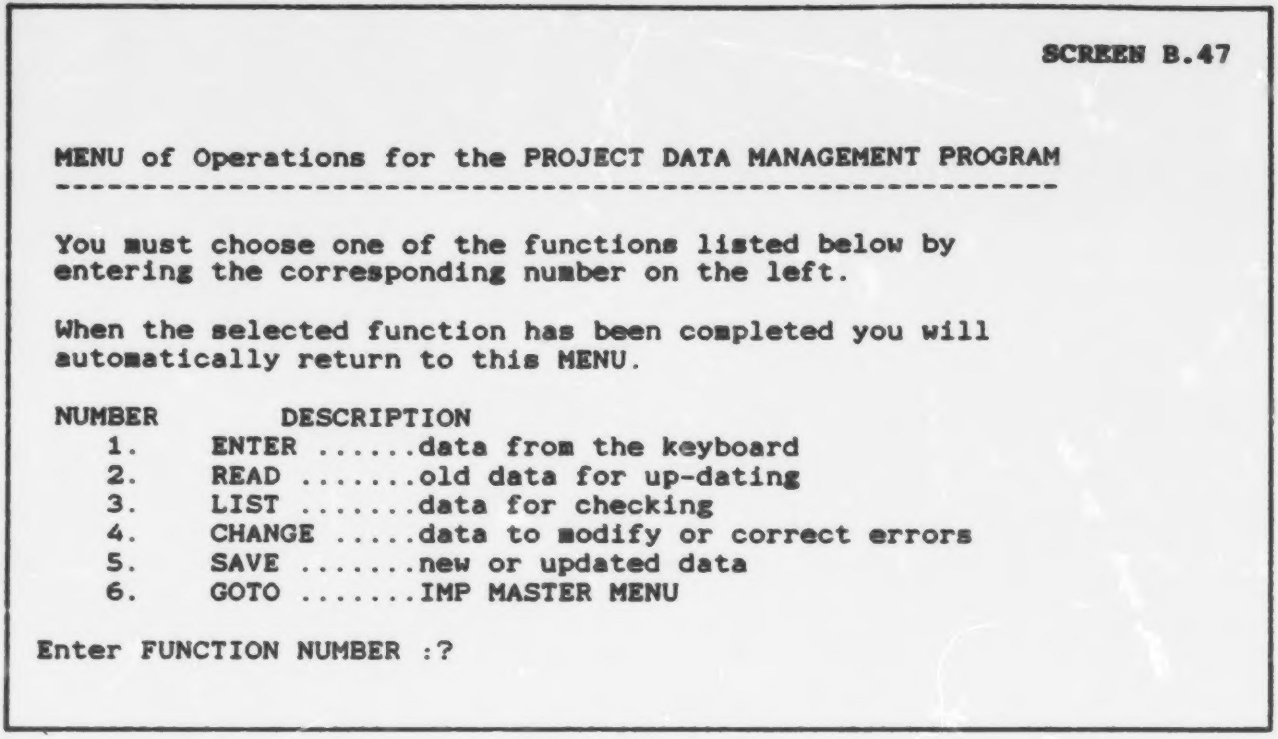
SCREEN B.45

```
POP1
PROJECT ORIENTED PROGRAM FOR POWER STUDIES
DATA MANAGEMENT PROGRAM




August 23, 1988




CHARLES HOWARD & ASSOCIATES LTD.
300 - 1144 FORT STREET
VICTORIA, B.C., V8V 3K8
```

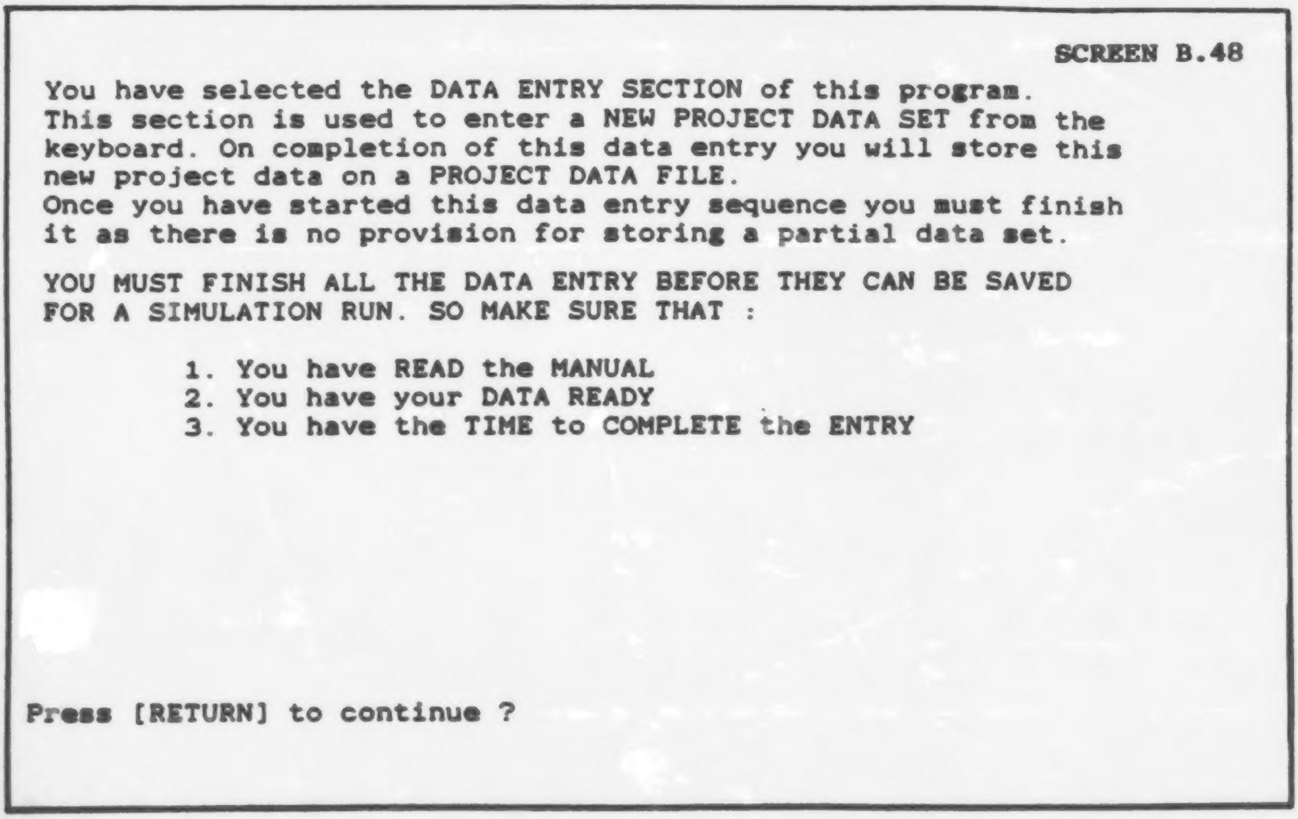


SCREEN B.46

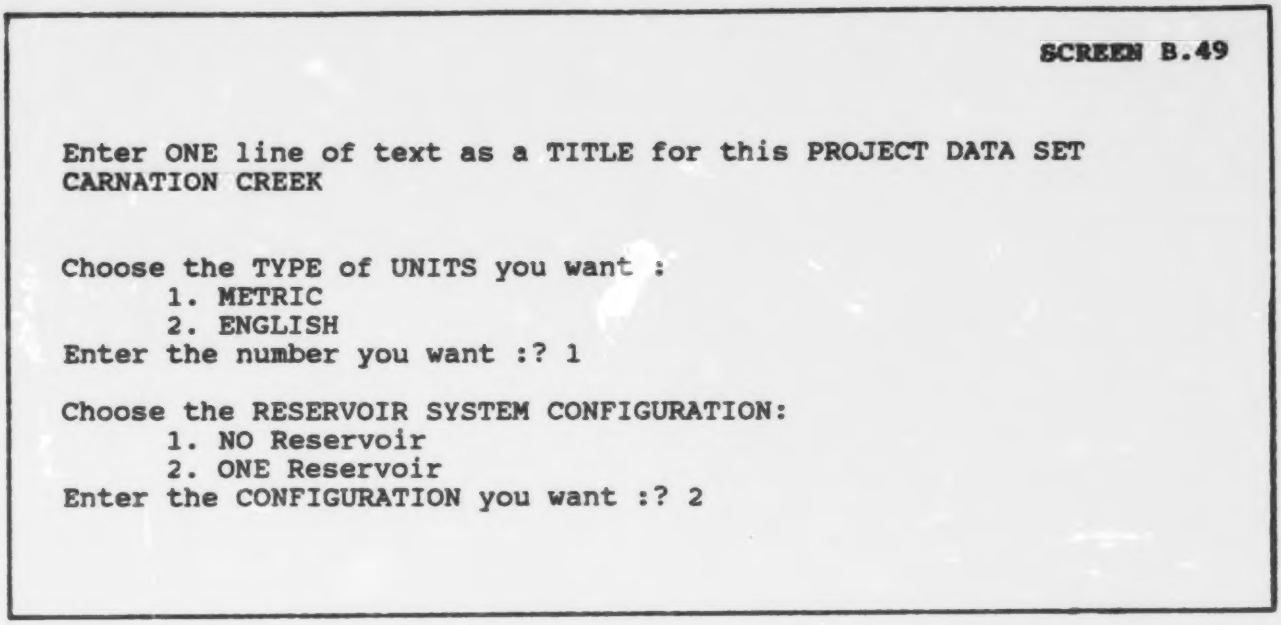
```
NORMAL STEPS IN USING THE PROGRAM
     1.  Enter your data through the keyboard by hand.
     2.  List your data to check for errors.
     3.  Correct any errors in your data.
     4.  Save the data on disk for future simulations.
         (The data file can be up-dated by the changes routine.)
     5.  Continue on to the actual simulation.

You do not have to follow any particular order
because you will have control of the order in which these
functions are executed by using the MENU PROGRAM.




Press  RETURN  to continue ?
```



```
                                                              SCREEN B.47


  MENU of Operations for the PROJECT DATA MANAGEMENT PROGRAM
  ----------------------------------------------------------

  You must choose one of the functions listed below by
  entering the corresponding number on the left.

  When the selected function has been completed you will
  automatically return to this MENU.

  NUMBER       DESCRIPTION
     1.     ENTER ......data from the keyboard
     2.     READ .......old data for up-dating
     3.     LIST .......data for checking
     4.     CHANGE .....data to modify or correct errors
     5.     SAVE .......new or updated data
     6.     GOTO .......IMP MASTER MENU

 Enter FUNCTION NUMBER :?
```

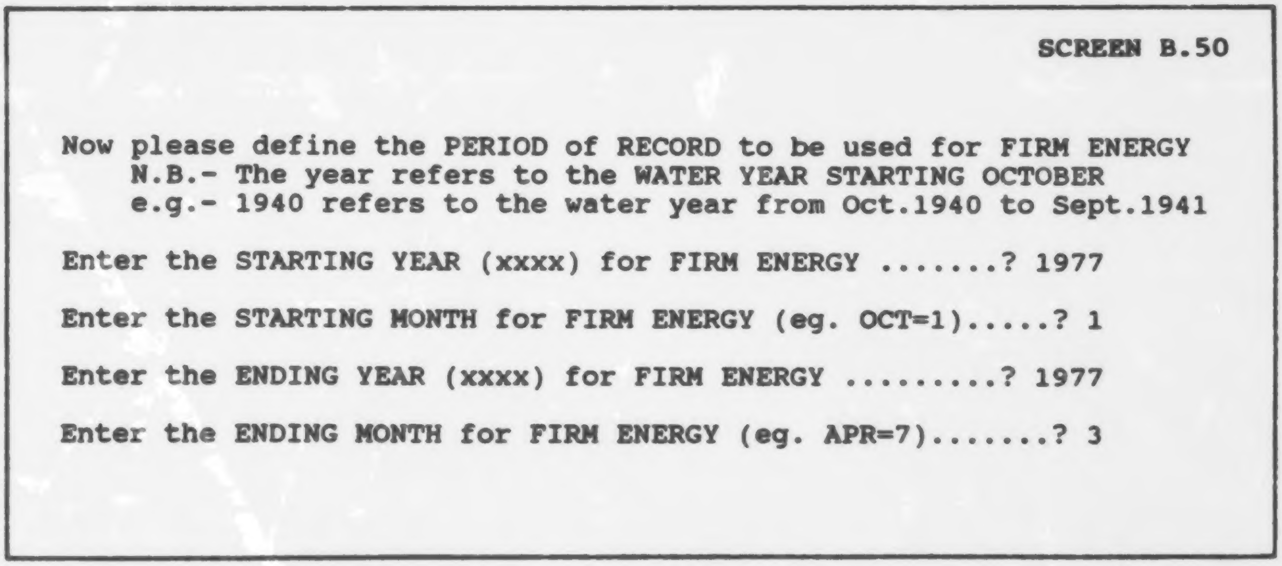


```
                                                              SCREEN B.48
 You have selected the DATA ENTRY SECTION of this program.
 This section is used to enter a NEW PROJECT DATA SET from the
 keyboard. On completion of this data entry you will store this
 new project data on a PROJECT DATA FILE.
 Once you have started this data entry sequence you must finish
 it as there is no provision for storing a partial data set.

 YOU MUST FINISH ALL THE DATA ENTRY BEFORE THEY CAN BE SAVED
 FOR A SIMULATION RUN. SO MAKE SURE THAT :

        1. You have READ the MANUAL
        2. You have your DATA READY
        3. You have the TIME to COMPLETE the ENTRY







Press [RETURN] to continue ?
```



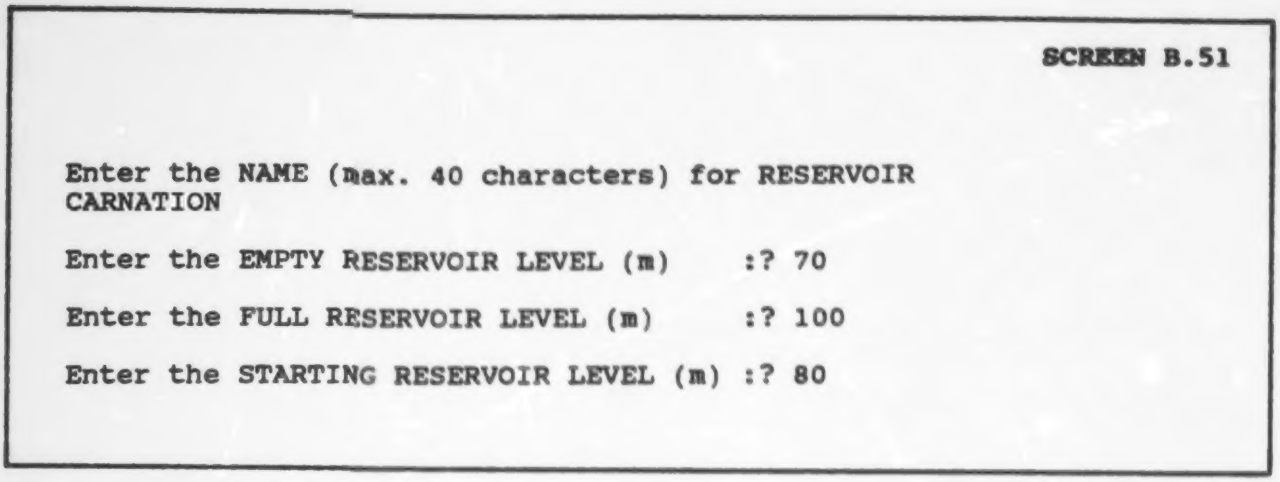
SCREEN B.49

```
Enter ONE line of text as a TITLE for this PROJECT DATA SET
CARNATION CREEK


Choose the TYPE of UNITS you want :
      1. METRIC
      2. ENGLISH
Enter the number you want :? 1

Choose the RESERVOIR SYSTEM CONFIGURATION:
      1. NO Reservoir
      2. ONE Reservoir
Enter the CONFIGURATION you want :? 2
```



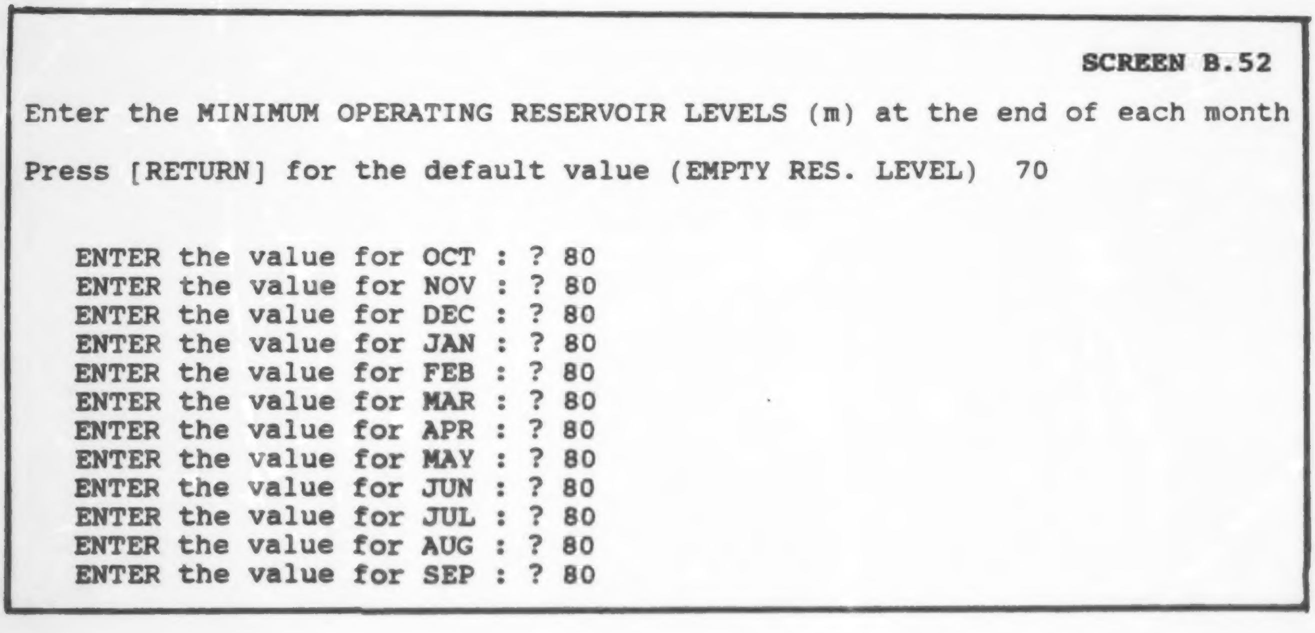
SCREEN B.50

```
Now please define the PERIOD of RECORD to be used for FIRM ENERGY
    N.B.- The year refers to the WATER YEAR STARTING OCTOBER
    e.g.- 1940 refers to the water year from Oct.1940 to Sept.1941

Enter the STARTING YEAR (xxxx) for FIRM ENERGY .......? 1977

Enter the STARTING MONTH for FIRM ENERGY (eg. OCT=1).....? 1

Enter the ENDING YEAR (xxxx) for FIRM ENERGY .........? 1977

Enter the ENDING MONTH for FIRM ENERGY (eg. APR=7).......? 3
```



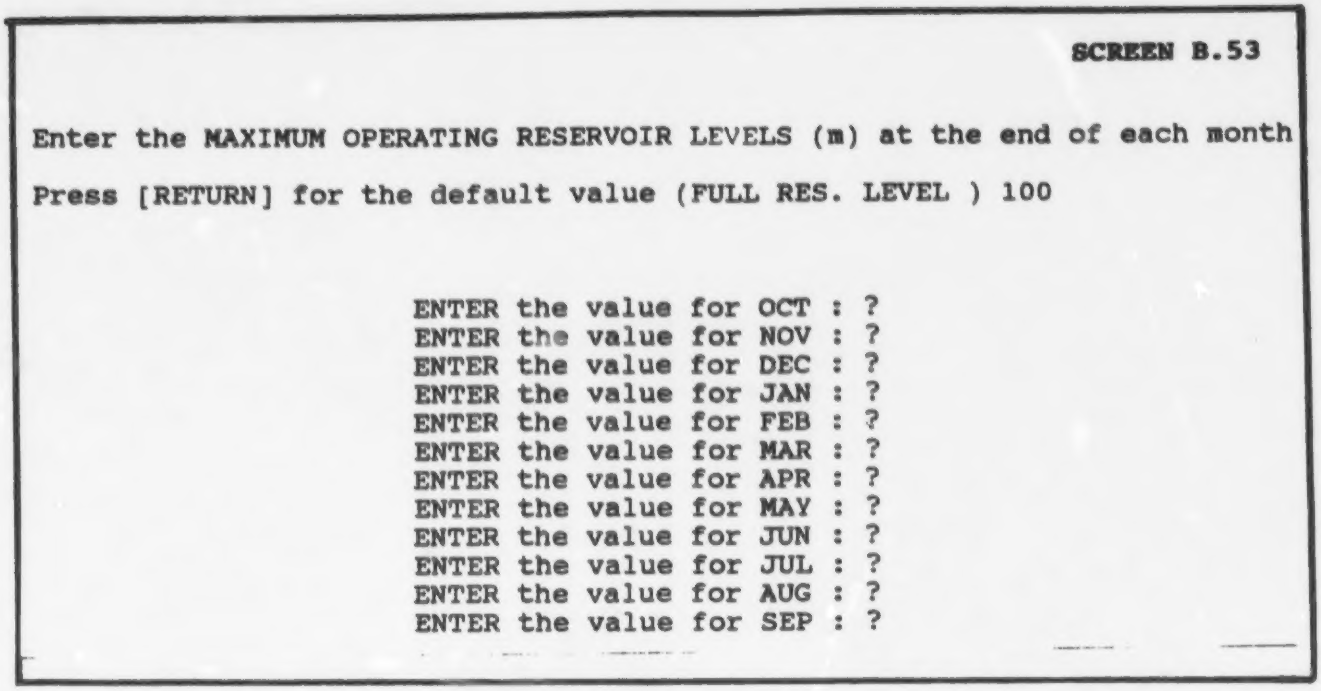
SCREEN B.51

```
Enter the NAME (max. 40 characters) for RESERVOIR
CARNATION

Enter the EMPTY RESERVOIR LEVEL (m)    :? 70

Enter the FULL RESERVOIR LEVEL (m)     :? 100

Enter the STARTING RESERVOIR LEVEL (m) :? 80
```

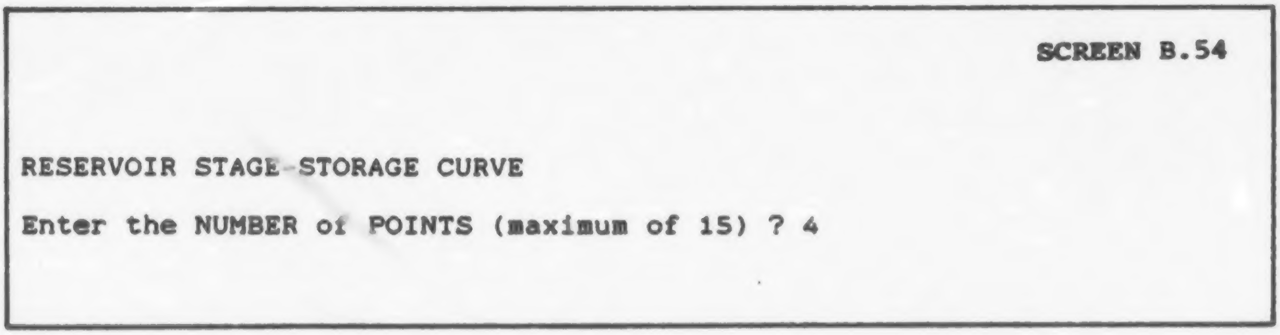


SCREEN B.52

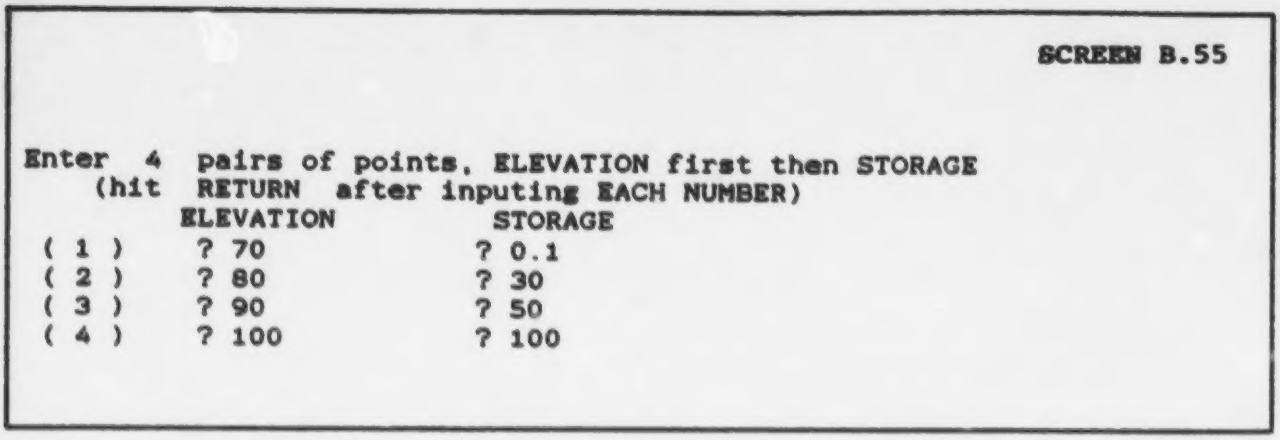
```
Enter the MINIMUM OPERATING RESERVOIR LEVELS (m) at the end of each month

Press [RETURN] for the default value (EMPTY RES. LEVEL)  70


   ENTER the value for OCT : ? 80
   ENTER the value for NOV : ? 80
   ENTER the value for DEC : ? 80
   ENTER the value for JAN : ? 80
   ENTER the value for FEB : ? 80
   ENTER the value for MAR : ? 80
   ENTER the value for APR : ? 80
   ENTER the value for MAY : ? 80
   ENTER the value for JUN : ? 80
   ENTER the value for JUL : ? 80
   ENTER the value for AUG : ? 80
   ENTER the value for SEP : ? 80
```



```
                                                        SCREEN B.53

Enter the MAXIMUM OPERATING RESERVOIR LEVELS (m) at the end of each month

Press [RETURN] for the default value (FULL RES. LEVEL ) 100


                    ENTER the value for OCT : ?
                    ENTER the value for NOV : ?
                    ENTER the value for DEC : ?
                    ENTER the value for JAN : ?
                    ENTER the value for FEB : ?
                    ENTER the value for MAR : ?
                    ENTER the value for APR : ?
                    ENTER the value for MAY : ?
                    ENTER the value for JUN : ?
                    ENTER the value for JUL : ?
                    ENTER the value for AUG : ?
                    ENTER the value for SEP : ?
```

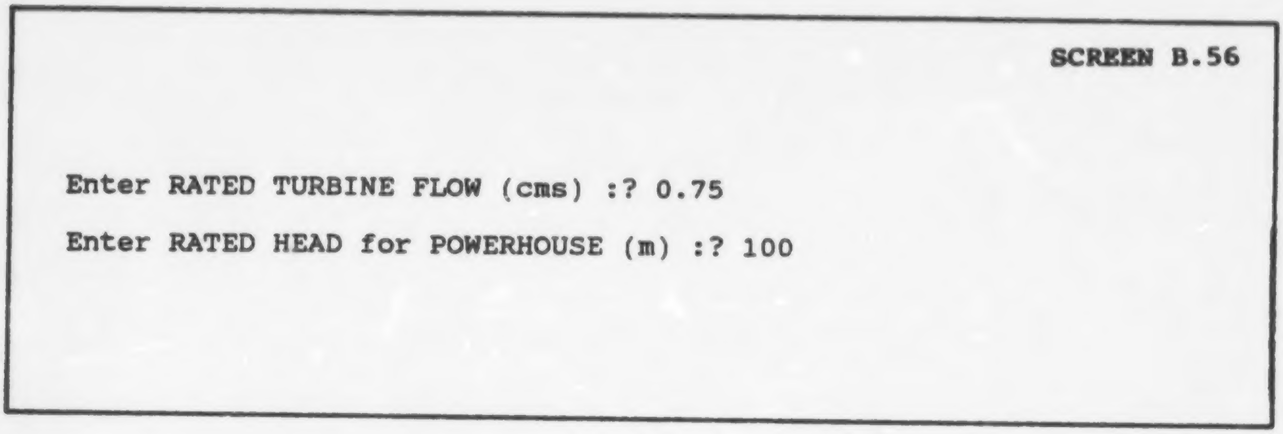


```
                                                        SCREEN B.54


RESERVOIR STAGE-STORAGE CURVE

Enter the NUMBER of POINTS (maximum of 15) ? 4
```



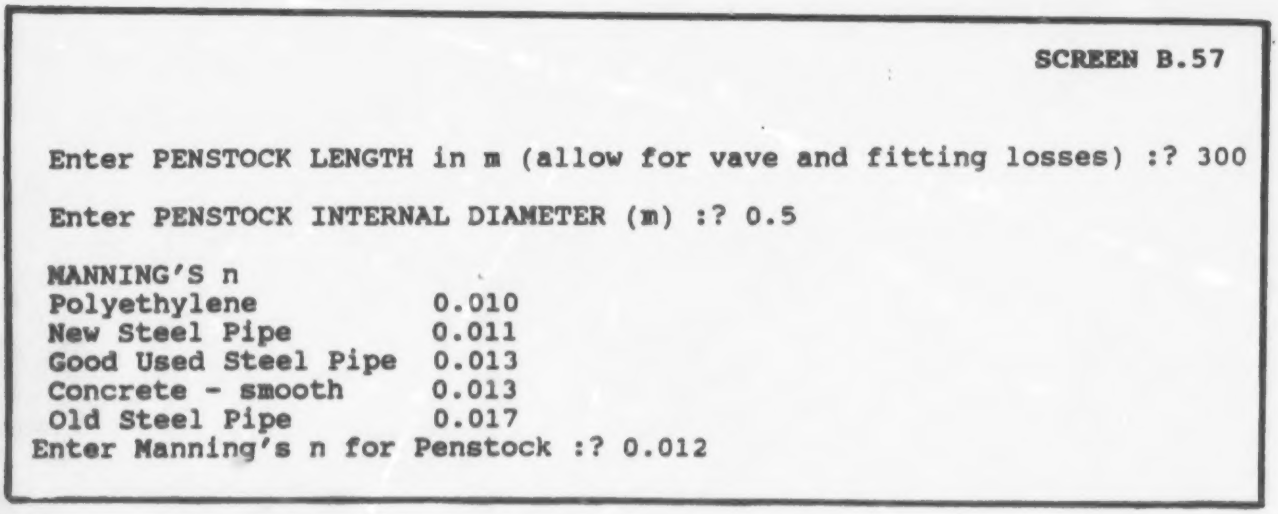
SCREEN B.55

```
Enter  4  pairs of points, ELEVATION first then STORAGE
    (hit  RETURN  after inputing EACH NUMBER)
         ELEVATION          STORAGE
 ( 1 )     ? 70             ? 0.1
 ( 2 )     ? 80             ? 30
 ( 3 )     ? 90             ? 50
 ( 4 )     ? 100            ? 100
```



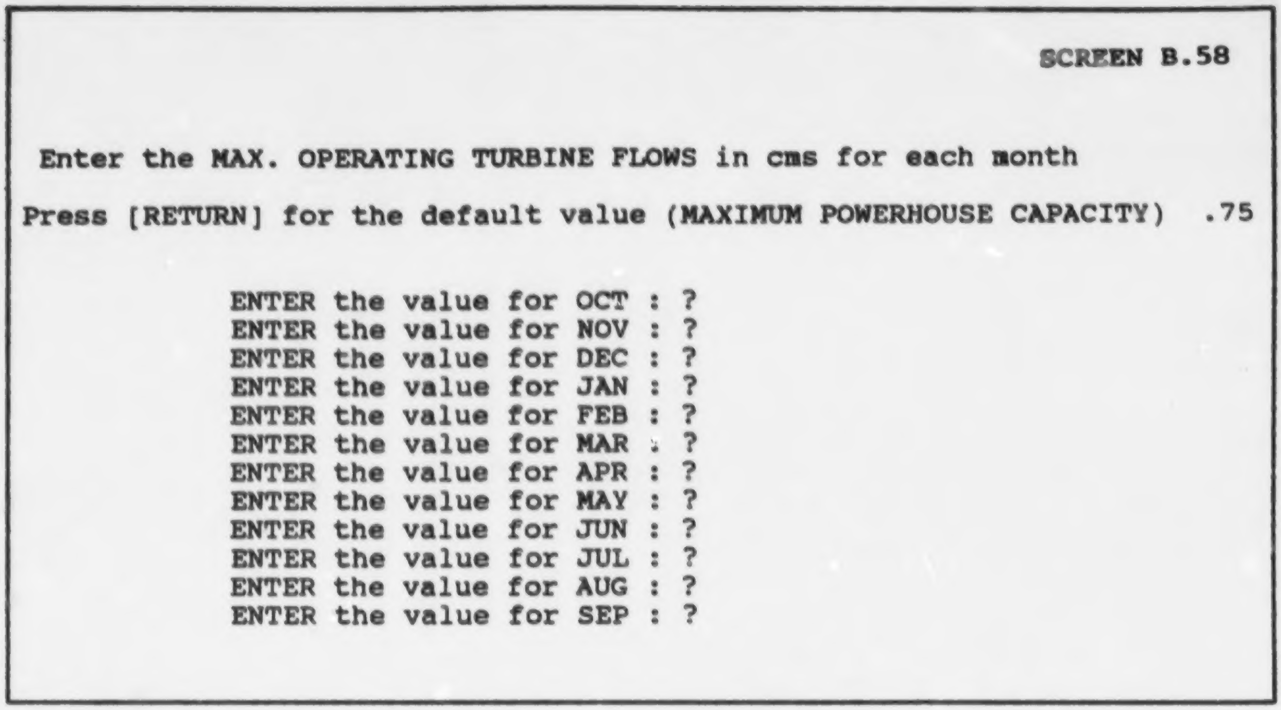
SCREEN B.56

```
  Enter RATED TURBINE FLOW (cms) :? 0.75

  Enter RATED HEAD for POWERHOUSE (m) :? 100
```

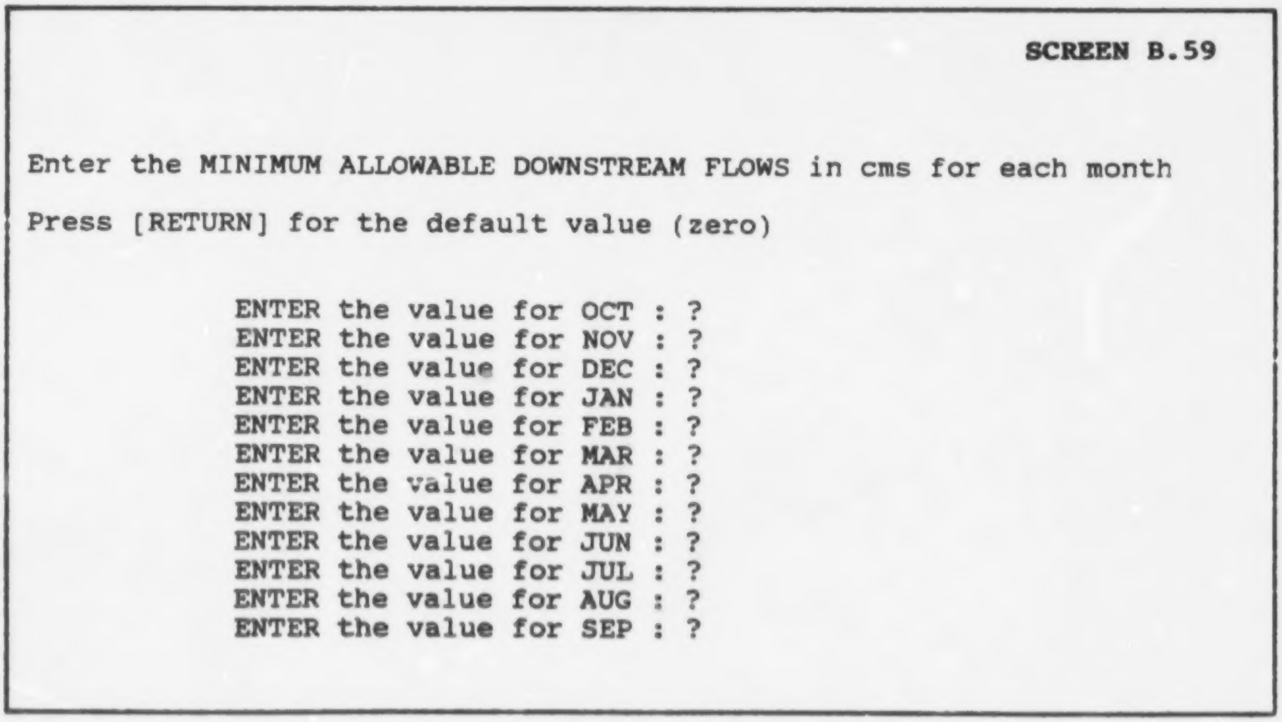


SCREEN B.57

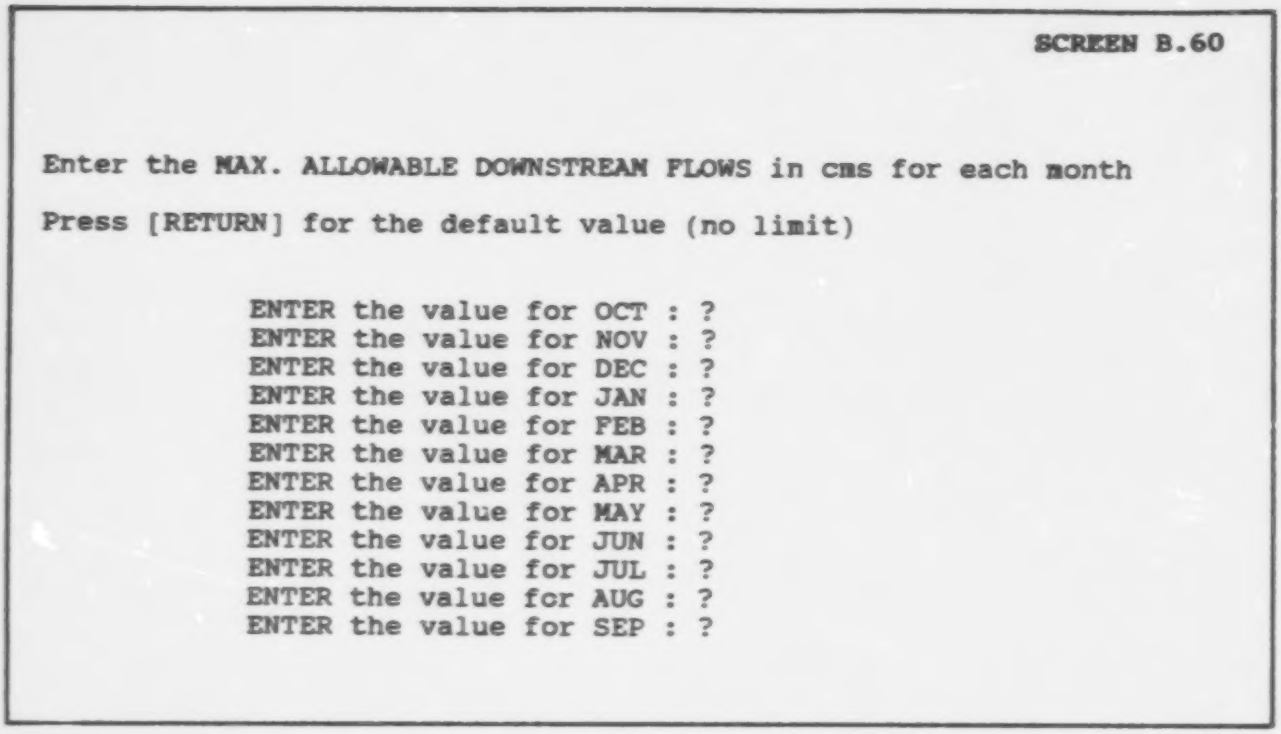
```
 Enter PENSTOCK LENGTH in m (allow for vave and fitting losses) :? 300

 Enter PENSTOCK INTERNAL DIAMETER (m) :? 0.5

 MANNING'S n
 Polyethylene           0.010
 New Steel Pipe         0.011
 Good Used Steel Pipe   0.013
 Concrete - smooth      0.013
 Old Steel Pipe         0.017
Enter Manning's n for Penstock :? 0.012
```



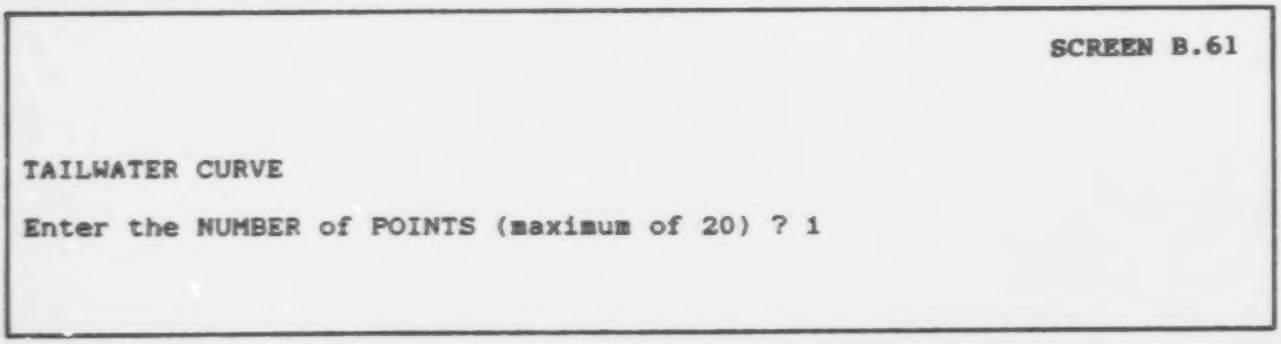
```
                                                        SCREEN B.58


 Enter the MAX. OPERATING TURBINE FLOWS in cms for each month

Press [RETURN] for the default value (MAXIMUM POWERHOUSE CAPACITY)  .75


          ENTER the value for OCT : ?
          ENTER the value for NOV : ?
          ENTER the value for DEC : ?
          ENTER the value for JAN : ?
          ENTER the value for FEB : ?
          ENTER the value for MAR : ?
          ENTER the value for APR : ?
          ENTER the value for MAY : ?
          ENTER the value for JUN : ?
          ENTER the value for JUL : ?
          ENTER the value for AUG : ?
          ENTER the value for SEP : ?
```



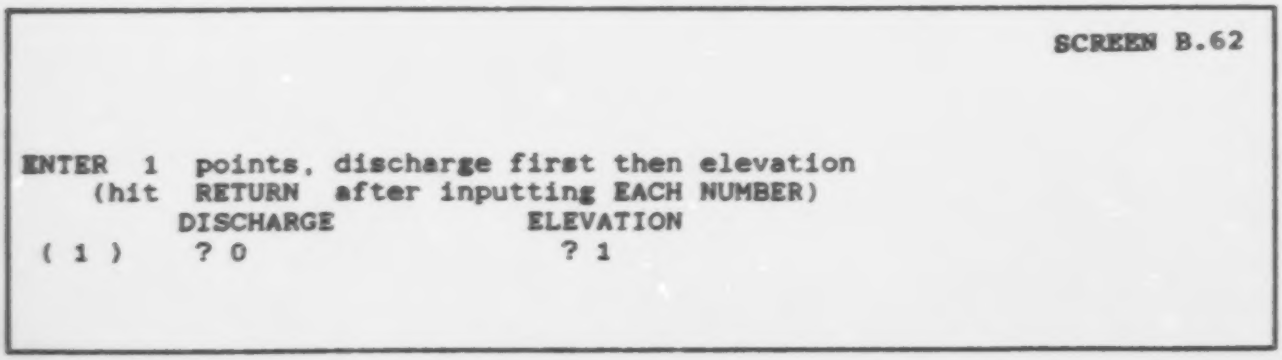
```
                                                        SCREEN B.59


Enter the MINIMUM ALLOWABLE DOWNSTREAM FLOWS in cms for each month

Press [RETURN] for the default value (zero)


          ENTER the value for OCT : ?
          ENTER the value for NOV : ?
          ENTER the value for DEC : ?
          ENTER the value for JAN : ?
          ENTER the value for FEB : ?
          ENTER the value for MAR : ?
          ENTER the value for APR : ?
          ENTER the value for MAY : ?
          ENTER the value for JUN : ?
          ENTER the value for JUL : ?
          ENTER the value for AUG : ?
          ENTER the value for SEP : ?
```



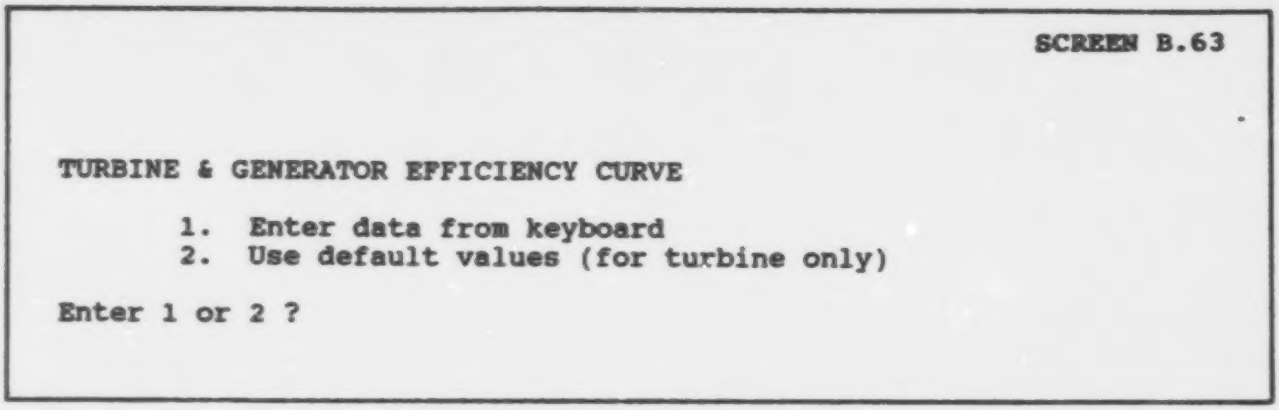
```
                                                          SCREEN B.60


 Enter the MAX. ALLOWABLE DOWNSTREAM FLOWS in cms for each month

 Press [RETURN] for the default value (no limit)

           ENTER the value for OCT : ?
           ENTER the value for NOV : ?
           ENTER the value for DEC : ?
           ENTER the value for JAN : ?
           ENTER the value for FEB : ?
           ENTER the value for MAR : ?
           ENTER the value for APR : ?
           ENTER the value for MAY : ?
           ENTER the value for JUN : ?
           ENTER the value for JUL : ?
           ENTER the value for AUG : ?
           ENTER the value for SEP : ?
```



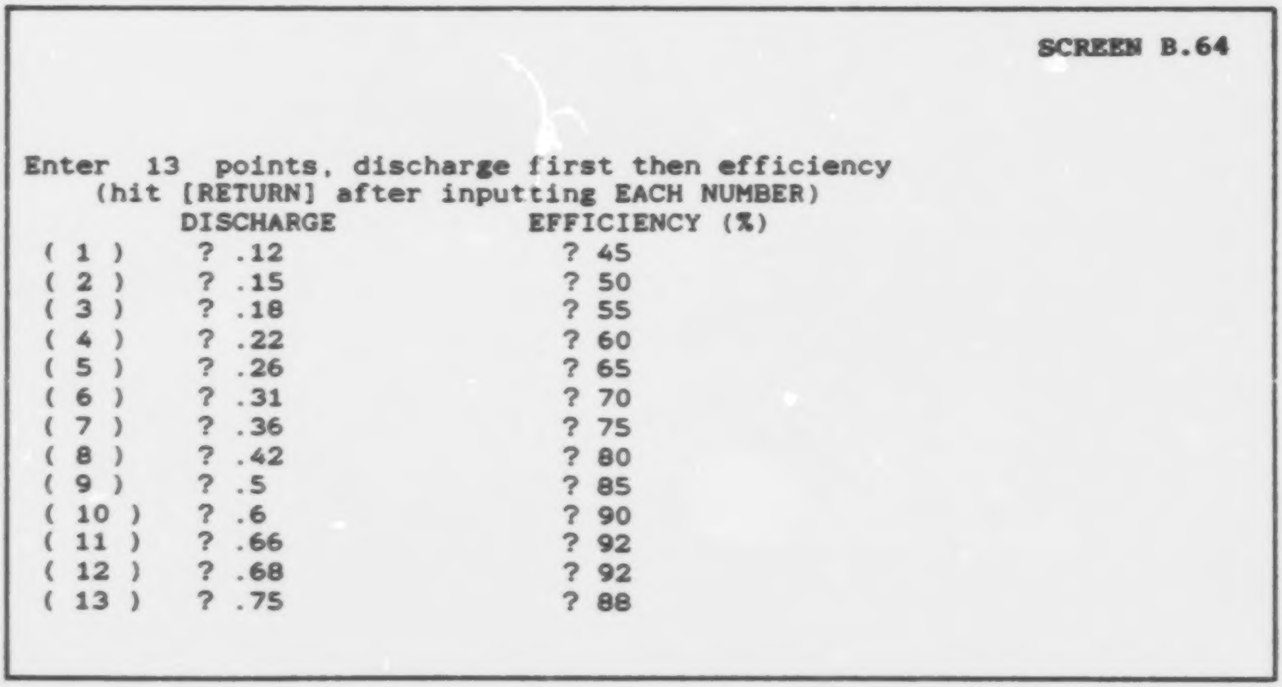
```
                                                          SCREEN B.61


TAILWATER CURVE

Enter the NUMBER of POINTS (maximum of 20) ? 1
```



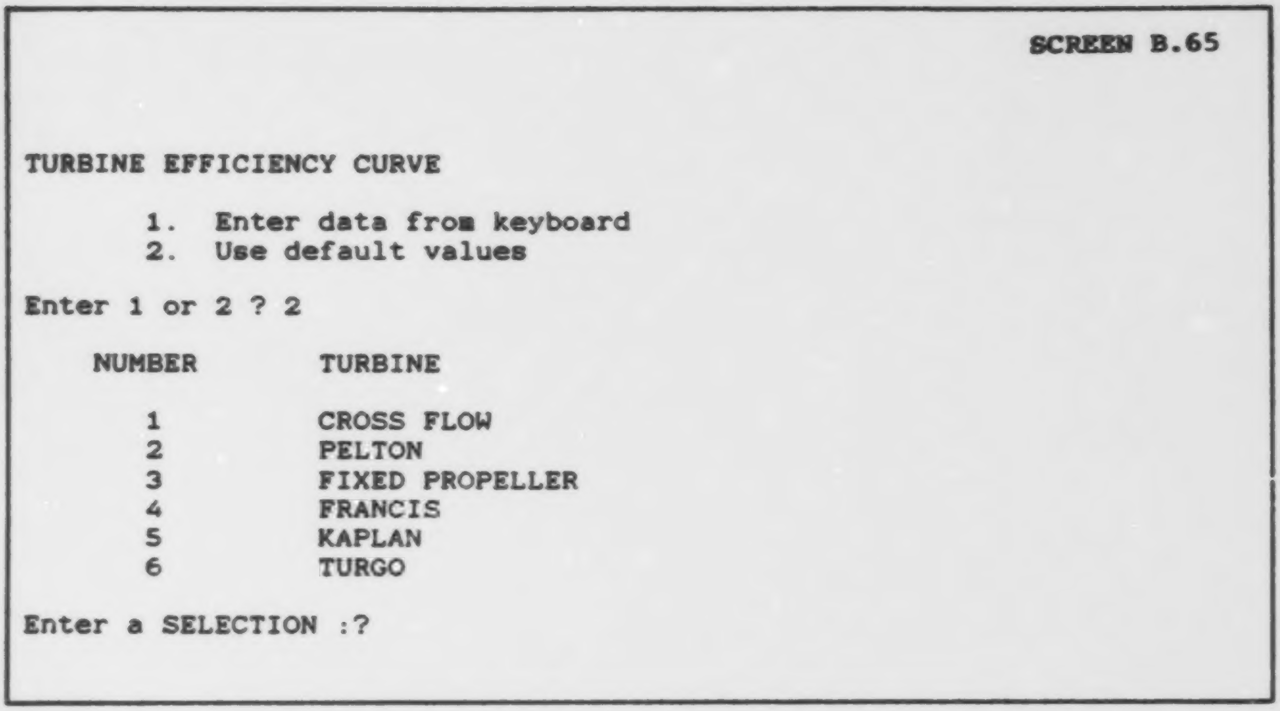
```
                                                          SCREEN B.62


ENTER  1  points, discharge first then elevation
    (hit  RETURN  after inputting EACH NUMBER)
         DISCHARGE              ELEVATION
 ( 1 )    ? 0                     ? 1
```



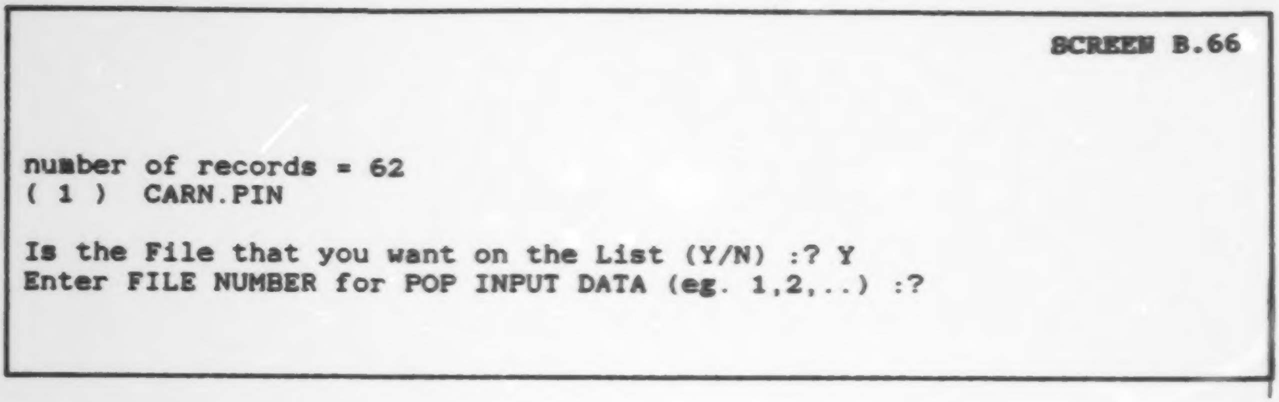
```
                                                    SCREEN B.63


  TURBINE & GENERATOR EFFICIENCY CURVE

         1.  Enter data from keyboard
         2.  Use default values (for turbine only)

  Enter 1 or 2 ?
```



```
                                                    SCREEN B.64



Enter  13  points, discharge first then efficiency
    (hit [RETURN] after inputting EACH NUMBER)
         DISCHARGE                   EFFICIENCY (%)
 ( 1 )     ? .12                       ? 45
 ( 2 )     ? .15                       ? 50
 ( 3 )     ? .18                       ? 55
 ( 4 )     ? .22                       ? 60
 ( 5 )     ? .26                       ? 65
 ( 6 )     ? .31                       ? 70
 ( 7 )     ? .36                       ? 75
 ( 8 )     ? .42                       ? 80
 ( 9 )     ? .5                        ? 85
 ( 10 )    ? .6                        ? 90
 ( 11 )    ? .66                       ? 92
 ( 12 )    ? .68                       ? 92
 ( 13 )    ? .75                       ? 88
```

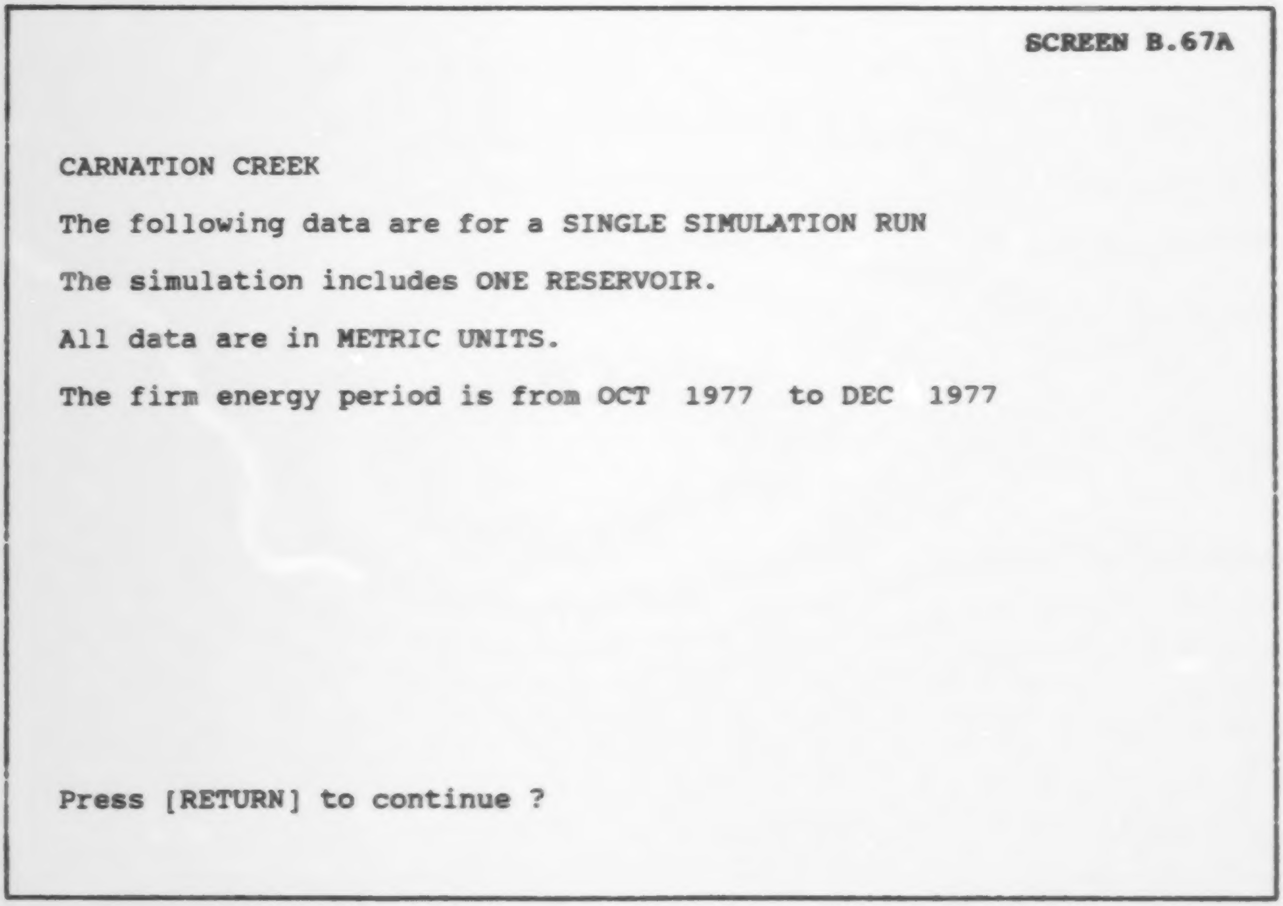


```
                                                                  SCREEN B.65


TURBINE EFFICIENCY CURVE

       1.  Enter data from keyboard
       2.  Use default values

Enter 1 or 2 ? 2

    NUMBER       TURBINE

       1         CROSS FLOW
       2         PELTON
       3         FIXED PROPELLER
       4         FRANCIS
       5         KAPLAN
       6         TURGO

Enter a SELECTION :?
```



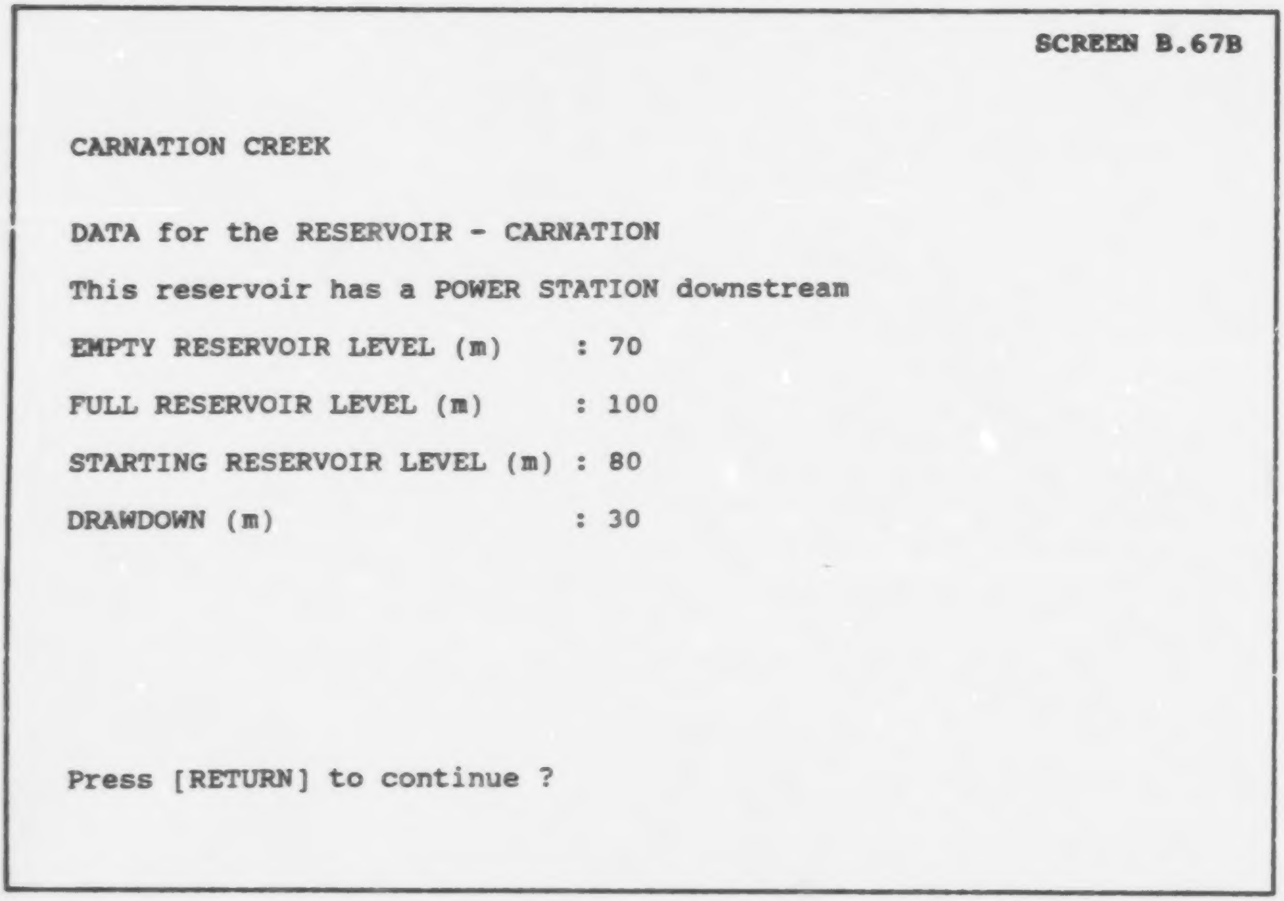
SCREEN B.66

```
number of records = 62
( 1 )  CARN.PIN

Is the File that you want on the List (Y/N) :? Y
Enter FILE NUMBER for POP INPUT DATA (eg. 1,2,..) :?
```

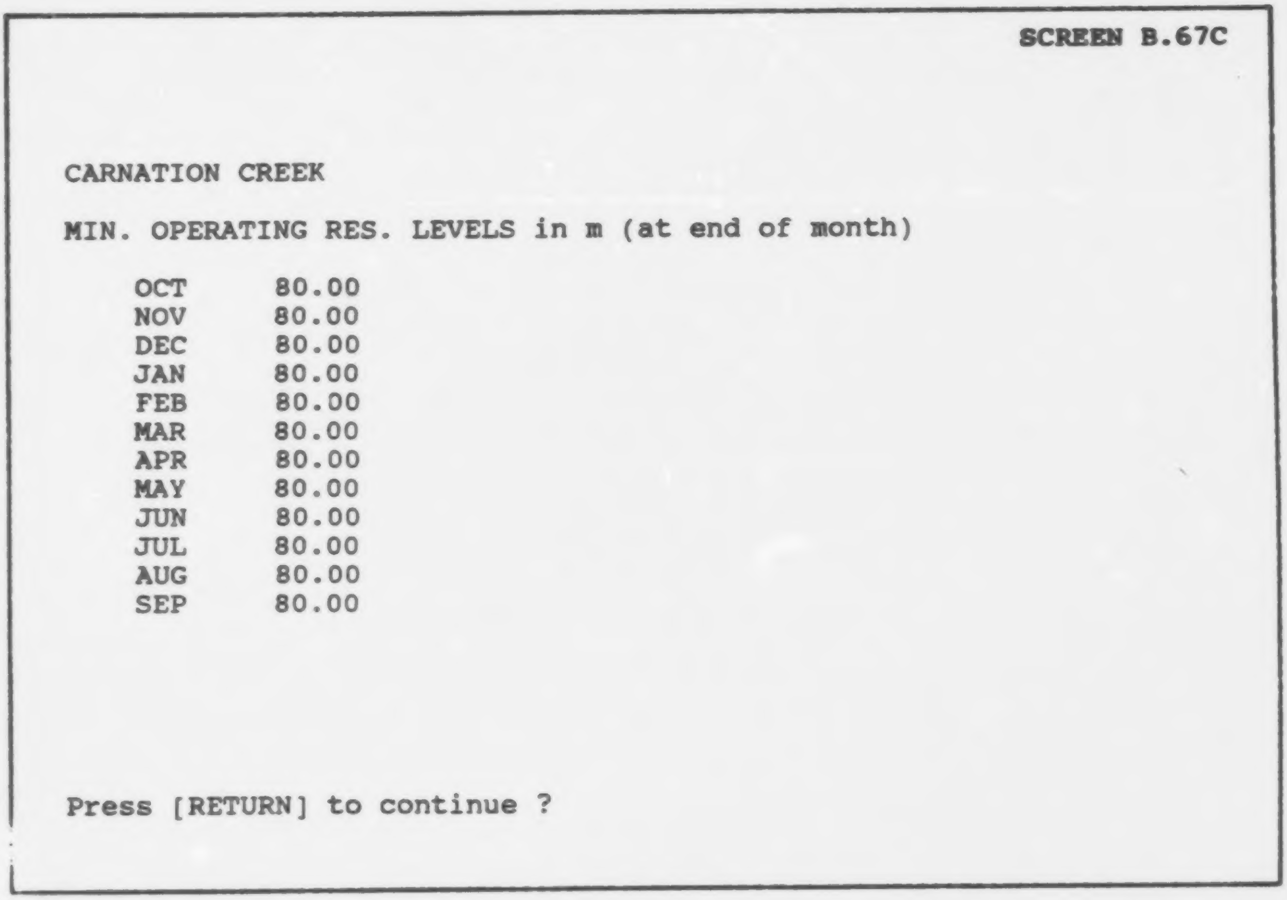


SCREEN B.67A

```
CARNATION CREEK

The following data are for a SINGLE SIMULATION RUN

The simulation includes ONE RESERVOIR.

All data are in METRIC UNITS.

The firm energy period is from OCT  1977  to DEC  1977









Press [RETURN] to continue ?
```

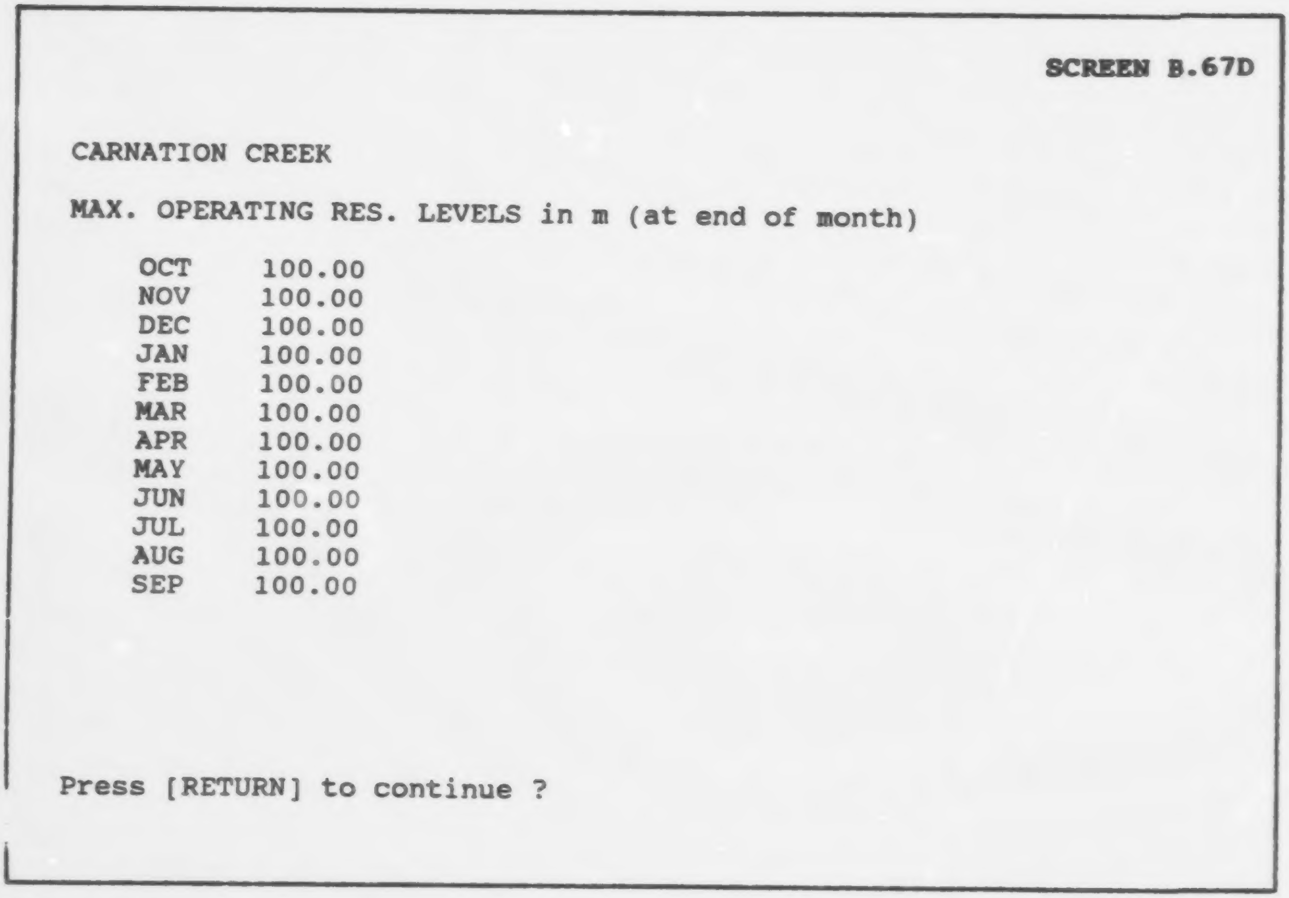


```
                                                    SCREEN B.67B

CARNATION CREEK

DATA for the RESERVOIR - CARNATION

This reservoir has a POWER STATION downstream

EMPTY RESERVOIR LEVEL (m)    : 70

FULL RESERVOIR LEVEL (m)     : 100

STARTING RESERVOIR LEVEL (m) : 80

DRAWDOWN (m)                 : 30




Press [RETURN] to continue ?
```

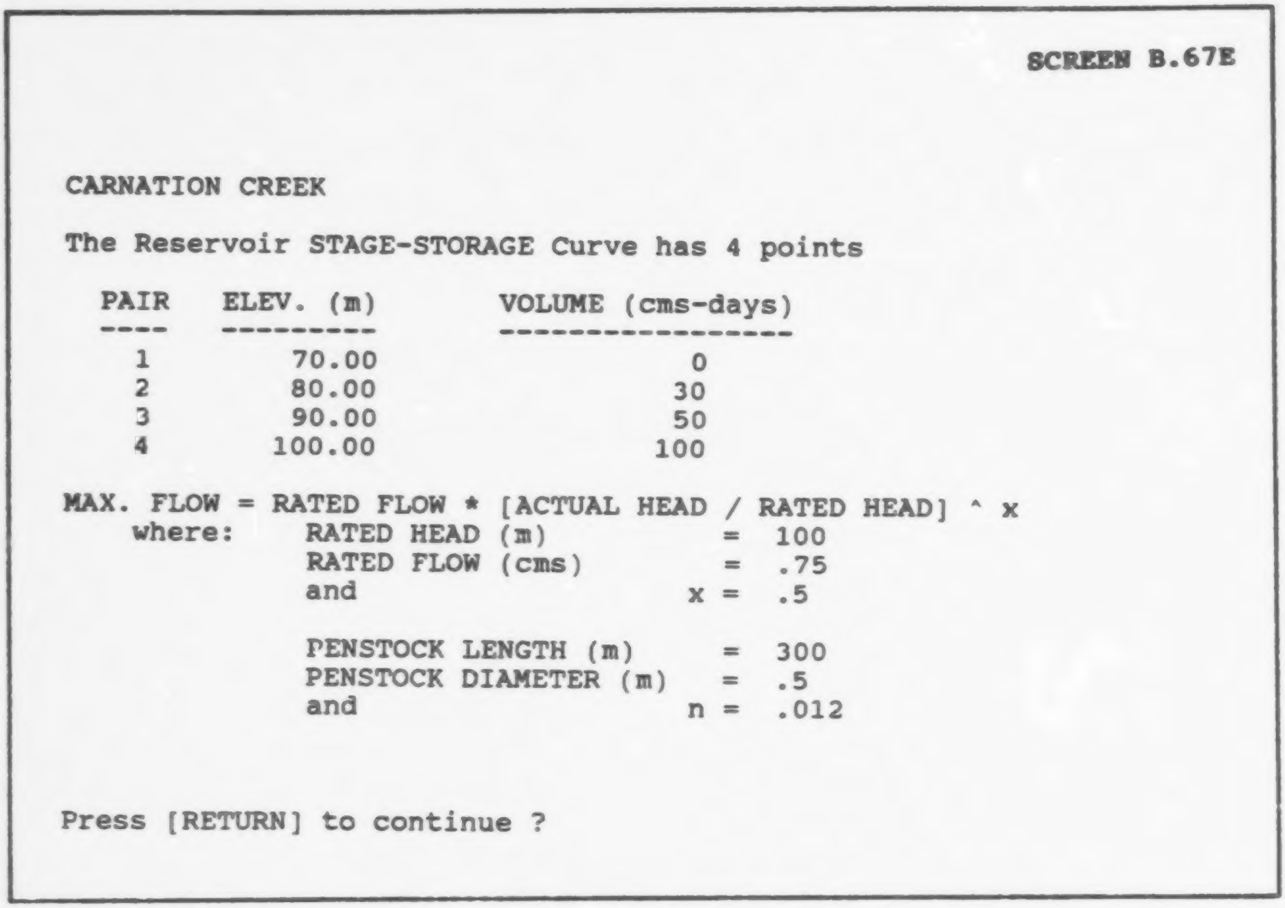


SCREEN B.67C

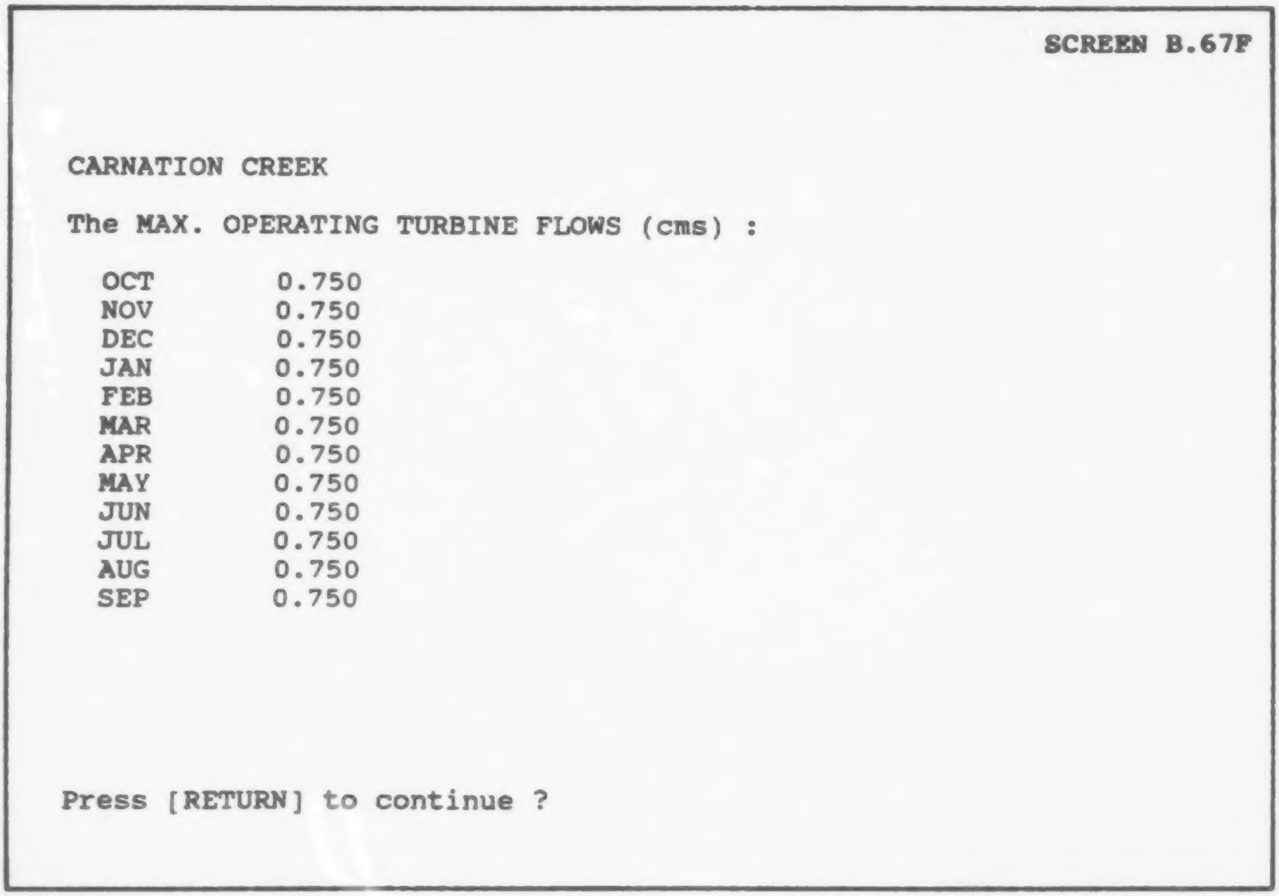
```
CARNATION CREEK

MIN. OPERATING RES. LEVELS in m (at end of month)

    OCT     80.00
    NOV     80.00
    DEC     80.00
    JAN     80.00
    FEB     80.00
    MAR     80.00
    APR     80.00
    MAY     80.00
    JUN     80.00
    JUL     80.00
    AUG     80.00
    SEP     80.00




Press [RETURN] to continue ?
```



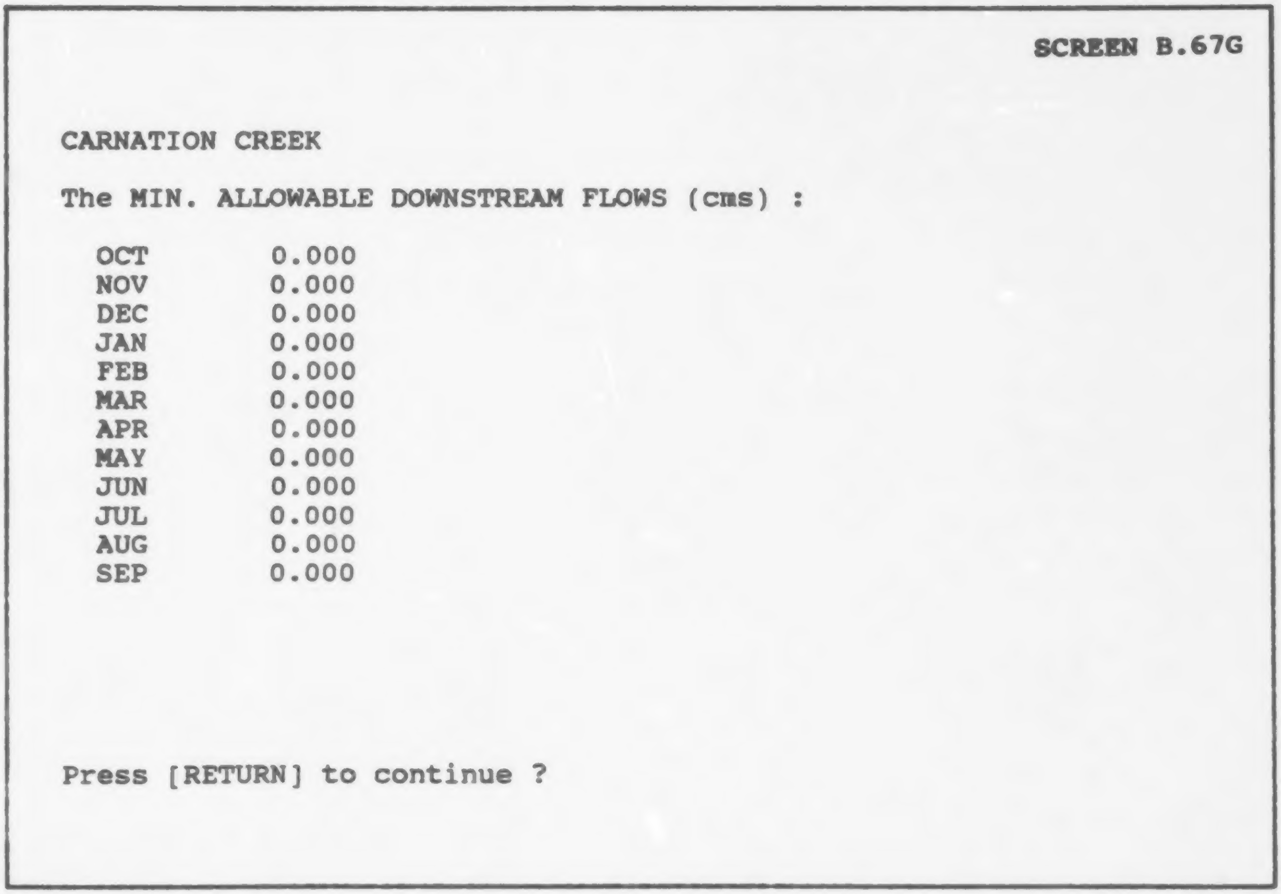
```
                                                   SCREEN B.67D

  CARNATION CREEK

  MAX. OPERATING RES. LEVELS in m (at end of month)

      OCT     100.00
      NOV     100.00
      DEC     100.00
      JAN     100.00
      FEB     100.00
      MAR     100.00
      APR     100.00
      MAY     100.00
      JUN     100.00
      JUL     100.00
      AUG     100.00
      SEP     100.00




  Press [RETURN] to continue ?
```



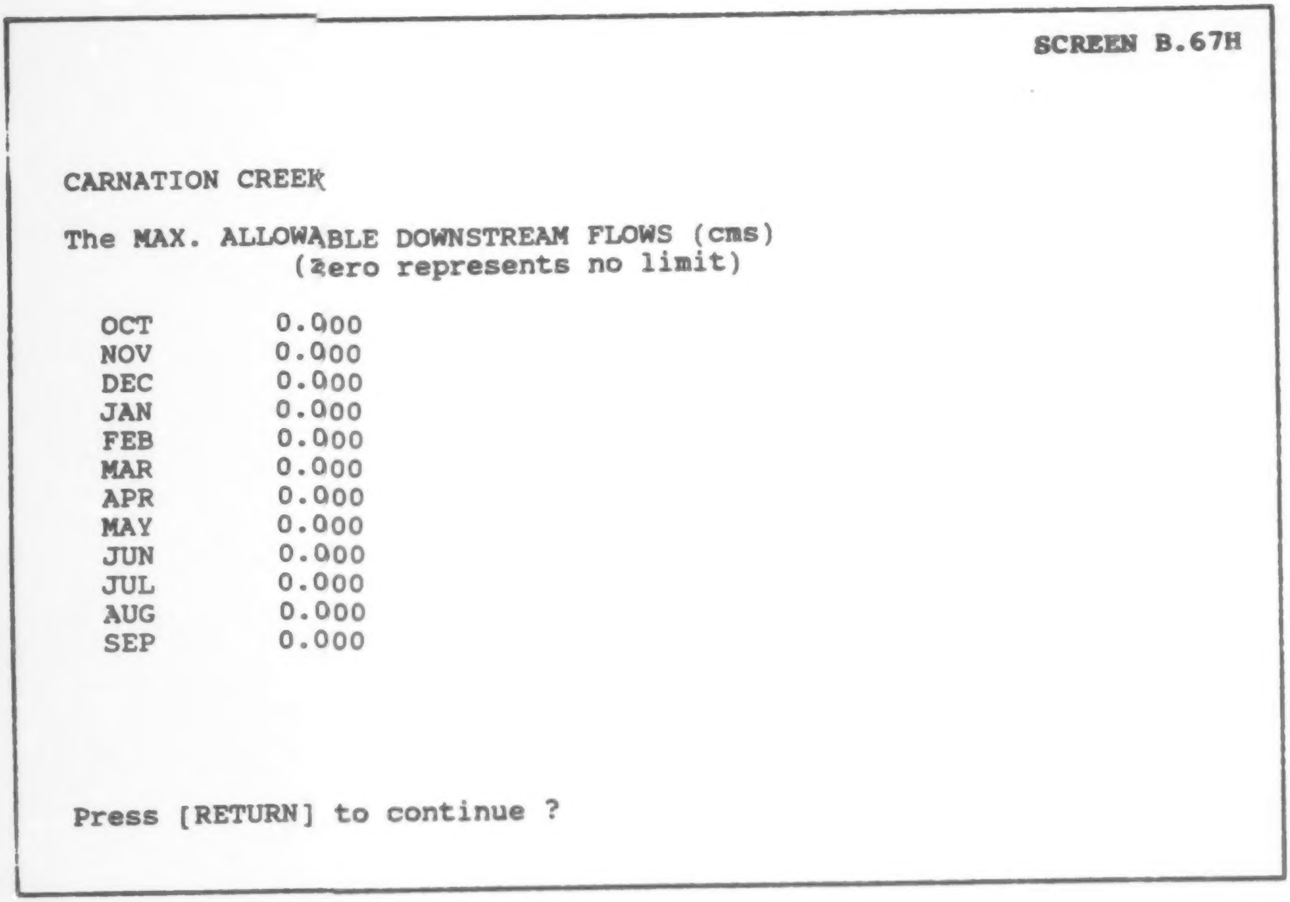
```
                                                         SCREEN B.67E


CARNATION CREEK

The Reservoir STAGE-STORAGE Curve has 4 points

  PAIR   ELEV. (m)       VOLUME (cms-days)
  ----   ---------       -----------------
    1       70.00                       0
    2       80.00                      30
    3       90.00                      50
    4      100.00                     100

MAX. FLOW = RATED FLOW * [ACTUAL HEAD / RATED HEAD] ^ x
    where:    RATED HEAD (m)            =  100
              RATED FLOW (cms)          =  .75
              and                     x =  .5

              PENSTOCK LENGTH (m)       =  300
              PENSTOCK DIAMETER (m)     =  .5
              and                     n =  .012


Press [RETURN] to continue ?
```



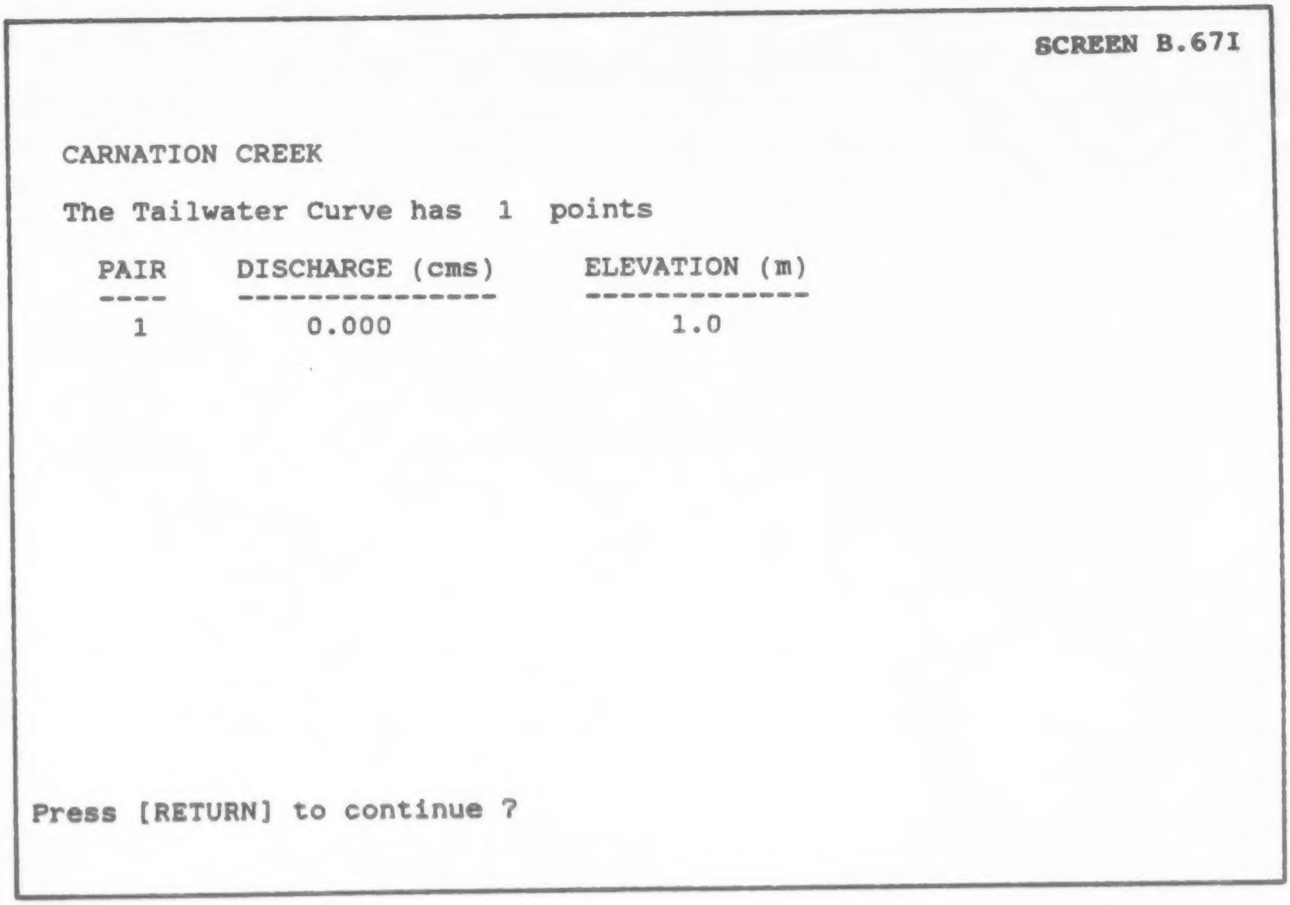
```
                                                          SCREEN B.67F


  CARNATION CREEK

  The MAX. OPERATING TURBINE FLOWS (cms) :

    OCT        0.750
    NOV        0.750
    DEC        0.750
    JAN        0.750
    FEB        0.750
    MAR        0.750
    APR        0.750
    MAY        0.750
    JUN        0.750
    JUL        0.750
    AUG        0.750
    SEP        0.750




  Press [RETURN] to continue ?
```



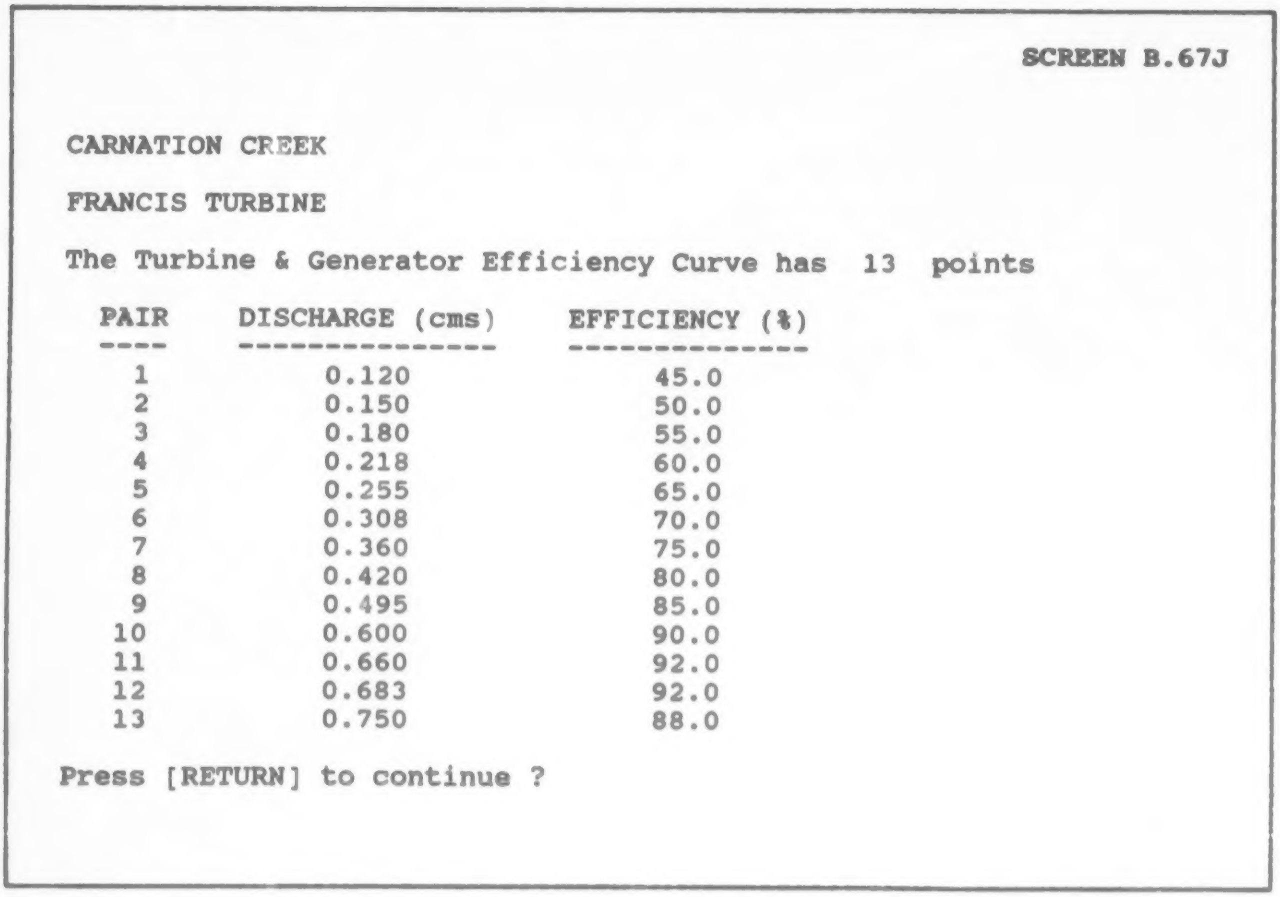
```
                                                     SCREEN B.67G

  CARNATION CREEK

  The MIN. ALLOWABLE DOWNSTREAM FLOWS (cms) :

    OCT       0.000
    NOV       0.000
    DEC       0.000
    JAN       0.000
    FEB       0.000
    MAR       0.000
    APR       0.000
    MAY       0.000
    JUN       0.000
    JUL       0.000
    AUG       0.000
    SEP       0.000




  Press [RETURN] to continue ?
```



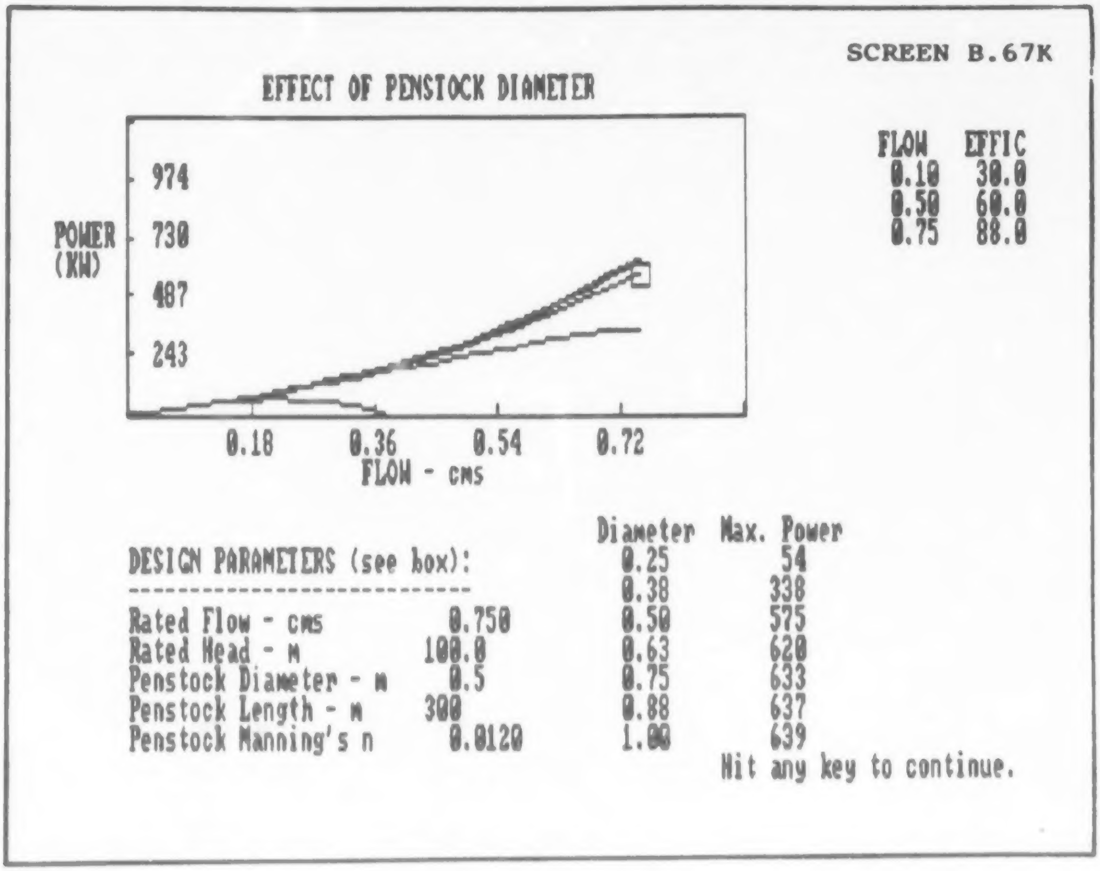
```
                                                          SCREEN B.67H



   CARNATION CREEK

   The MAX. ALLOWABLE DOWNSTREAM FLOWS (cms)
                (zero represents no limit)

     OCT        0.000
     NOV        0.000
     DEC        0.000
     JAN        0.000
     FEB        0.000
     MAR        0.000
     APR        0.000
     MAY        0.000
     JUN        0.000
     JUL        0.000
     AUG        0.000
     SEP        0.000




    Press [RETURN] to continue ?
```



```
                                                              SCREEN B.671


  CARNATION CREEK

  The Tailwater Curve has  1  points

    PAIR    DISCHARGE (cms)       ELEVATION (m)
    ----    ---------------       -------------
      1         0.000                  1.0









Press [RETURN] to continue ?
```



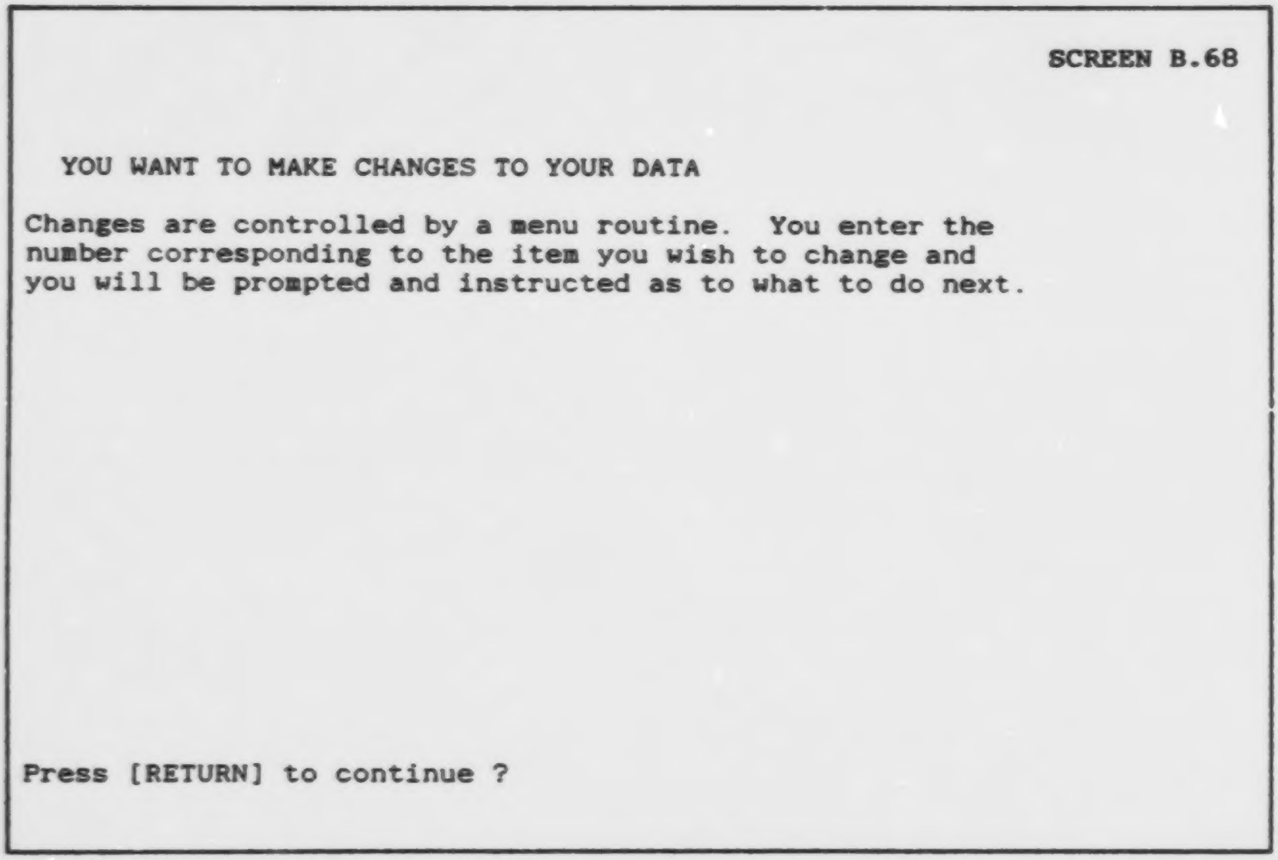
```
                                                         SCREEN B.67J


   CARNATION CREEK

   FRANCIS TURBINE

   The Turbine & Generator Efficiency Curve has  13  points

     PAIR     DISCHARGE (cms)     EFFICIENCY (%)
     ----     ---------------     --------------
       1           0.120               45.0
       2           0.150               50.0
       3           0.180               55.0
       4           0.218               60.0
       5           0.255               65.0
       6           0.308               70.0
       7           0.360               75.0
       8           0.420               80.0
       9           0.495               85.0
      10           0.600               90.0
      11           0.660               92.0
      12           0.683               92.0
      13           0.750               88.0

   Press [RETURN] to continue ?
```



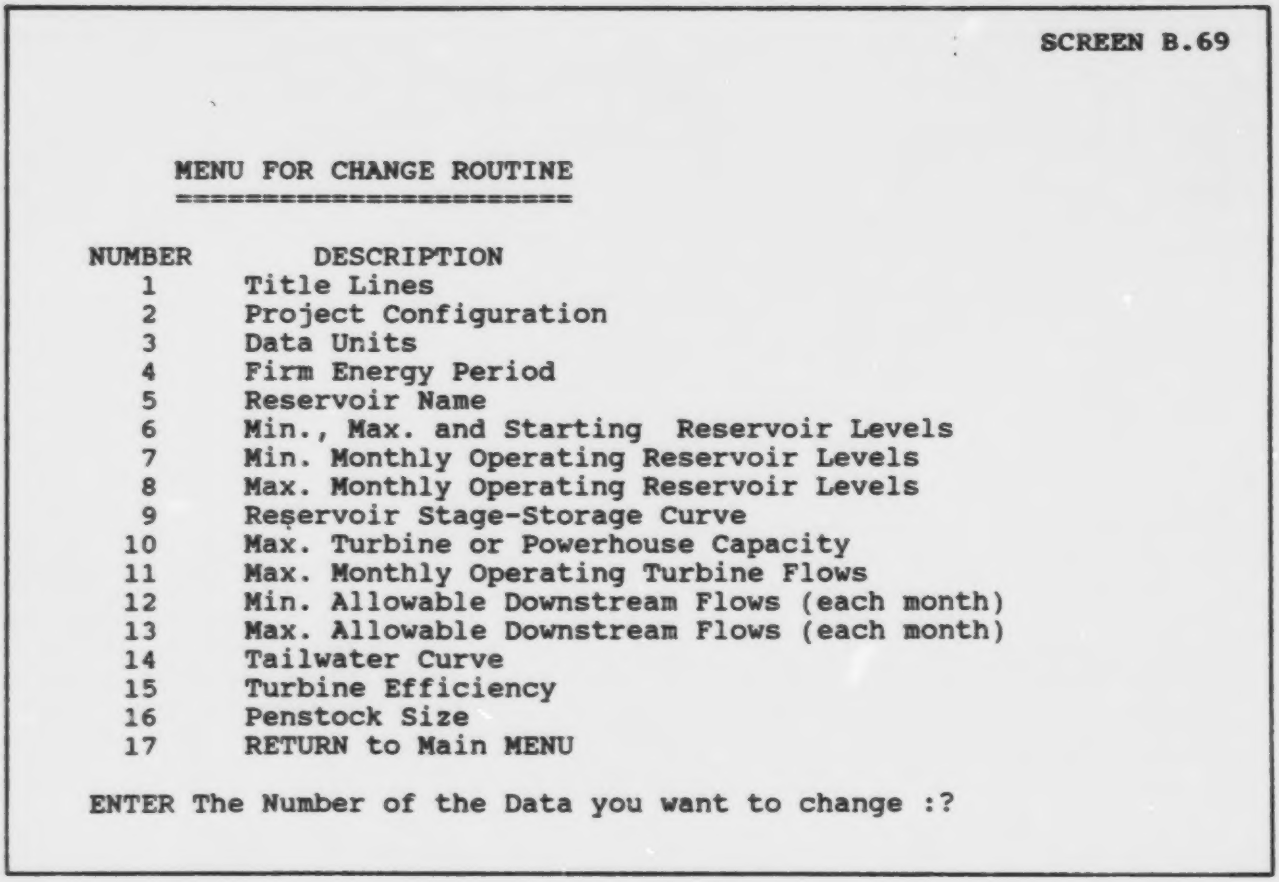
```
                                                        SCREEN B.67K
                EFFECT OF PENSTOCK DIAMETER

                                                       FLOW   EFFIC
                                                       0.10   30.0
                                                       0.50   60.0
                                                       0.75   88.0
```

POWER
(KW)
974
730
487
243
0.18
0.36
0.54
0.72
FLOW - cms

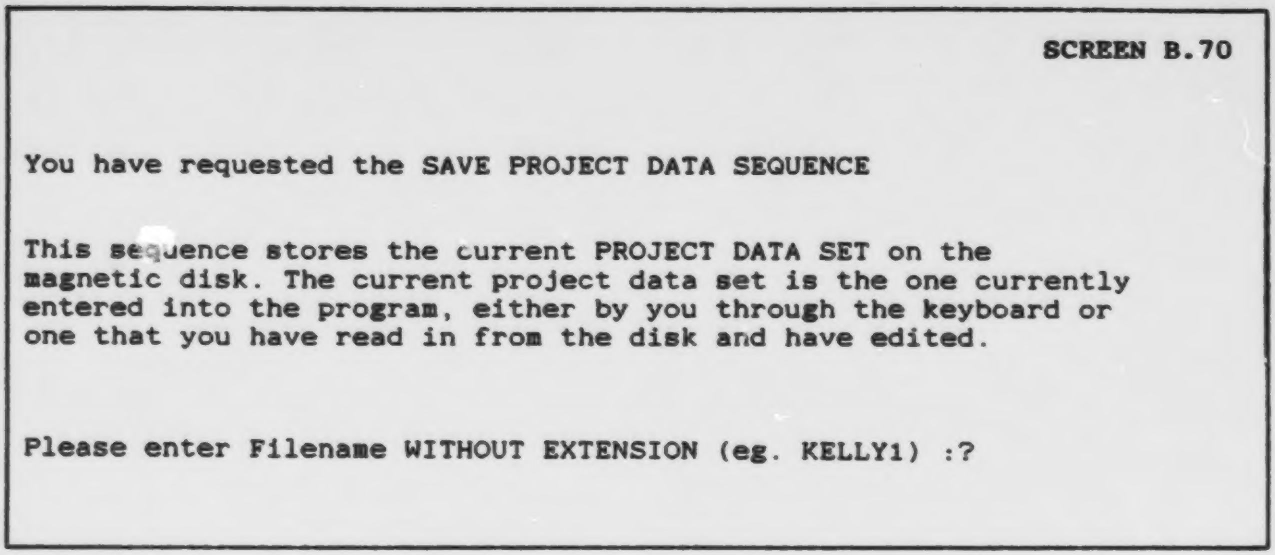
```
                                      Diameter  Max. Power
DESIGN PARAMETERS (see box):            0.25        54
----------------------------            0.38       338
Rated Flow - cms            0.750       0.50       575
Rated Head - m            100.0         0.63       620
Penstock Diameter - m       0.5         0.75       633
Penstock Length - m       300           0.88       637
Penstock Manning's n        0.0120      1.00       639
                                            Hit any key to continue.
```



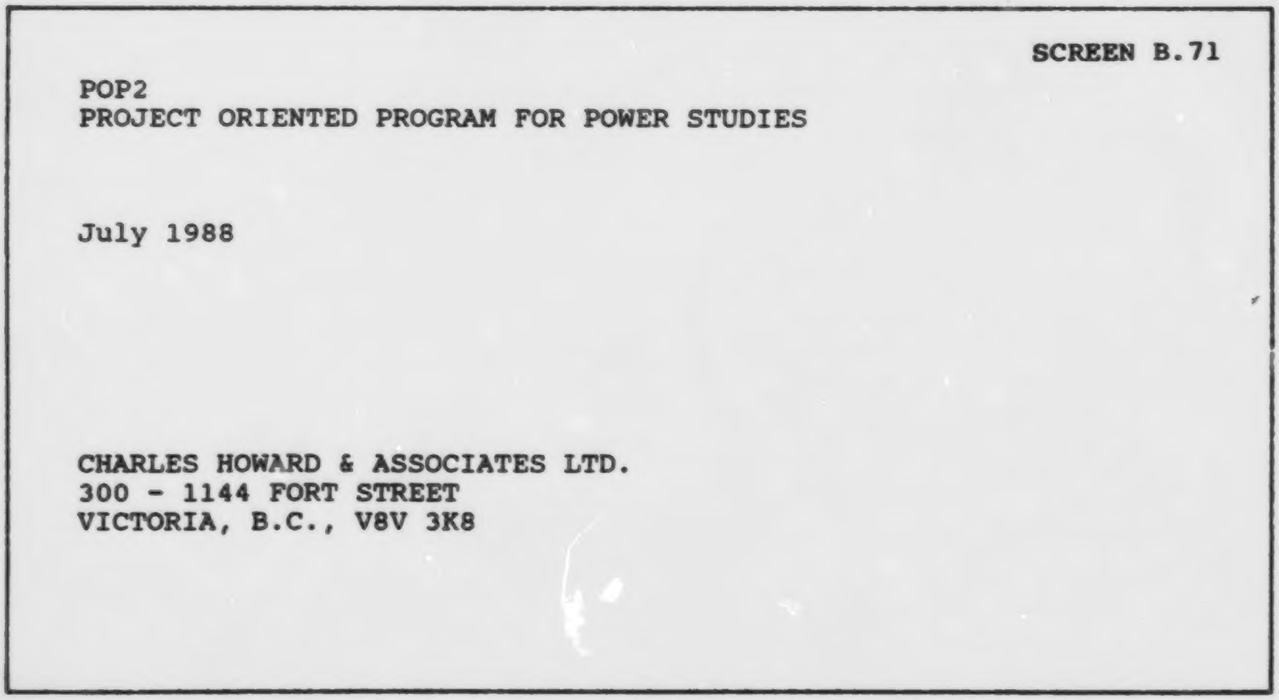
```
                                                    SCREEN B.68


  YOU WANT TO MAKE CHANGES TO YOUR DATA

Changes are controlled by a menu routine.  You enter the
number corresponding to the item you wish to change and
you will be prompted and instructed as to what to do next.











Press [RETURN] to continue ?
```



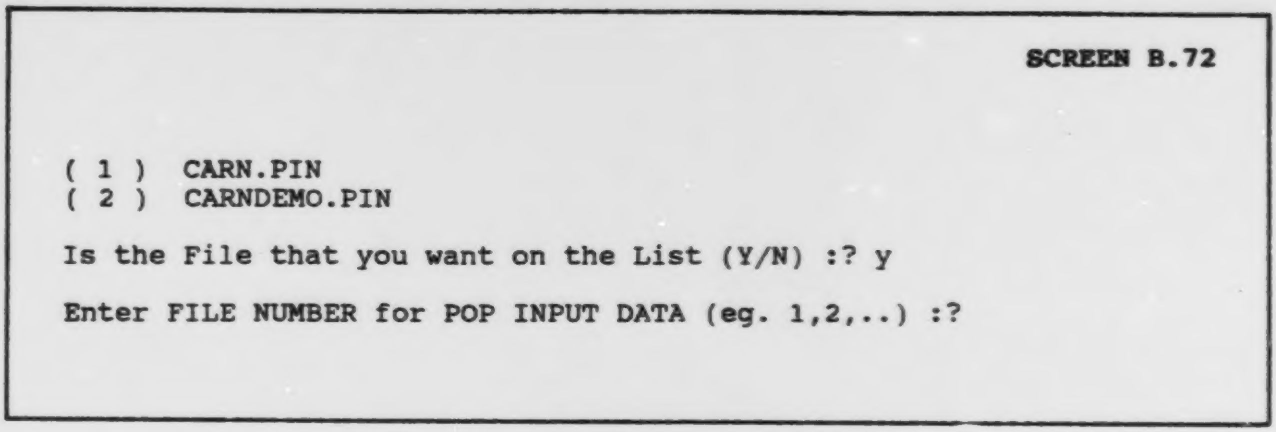
```
                                                    SCREEN B.69


       MENU FOR CHANGE ROUTINE
       =======================

NUMBER        DESCRIPTION
   1     Title Lines
   2     Project Configuration
   3     Data Units
   4     Firm Energy Period
   5     Reservoir Name
   6     Min., Max. and Starting  Reservoir Levels
   7     Min. Monthly Operating Reservoir Levels
   8     Max. Monthly Operating Reservoir Levels
   9     Reservoir Stage-Storage Curve
  10     Max. Turbine or Powerhouse Capacity
  11     Max. Monthly Operating Turbine Flows
  12     Min. Allowable Downstream Flows (each month)
  13     Max. Allowable Downstream Flows (each month)
  14     Tailwater Curve
  15     Turbine Efficiency
  16     Penstock Size
  17     RETURN to Main MENU

ENTER The Number of the Data you want to change :?
```



```
                                                        SCREEN B.70


You have requested the SAVE PROJECT DATA SEQUENCE


This sequence stores the current PROJECT DATA SET on the
magnetic disk. The current project data set is the one currently
entered into the program, either by you through the keyboard or
one that you have read in from the disk and have edited.


Please enter Filename WITHOUT EXTENSION (eg. KELLY1) :?
```

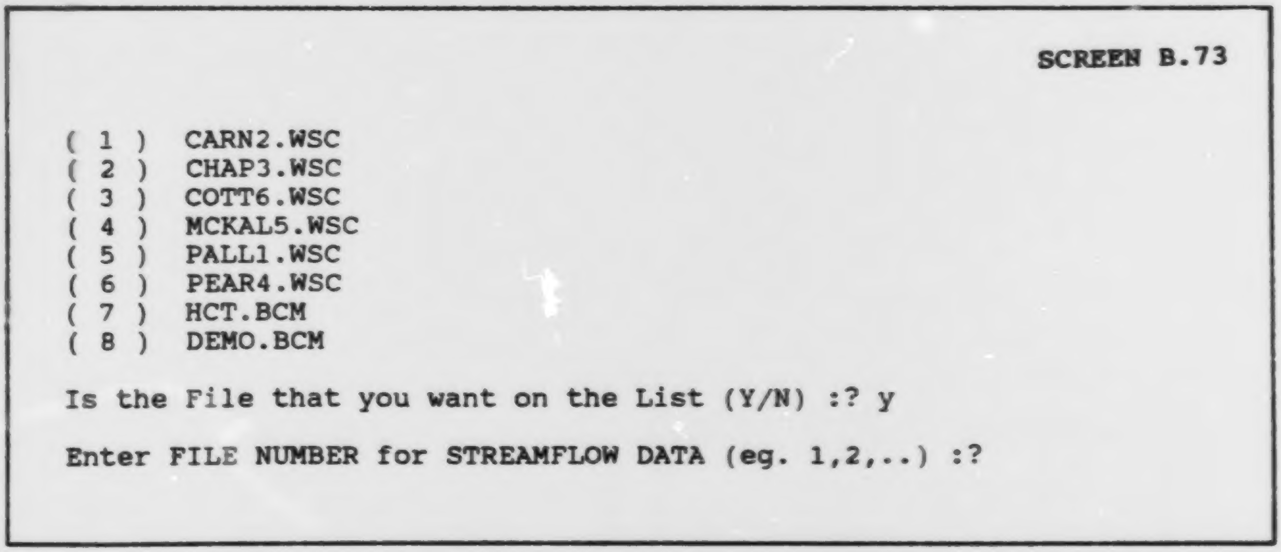


```
                                                        SCREEN B.71
   POP2
   PROJECT ORIENTED PROGRAM FOR POWER STUDIES


   July 1988



   CHARLES HOWARD & ASSOCIATES LTD.
   300 - 1144 FORT STREET
   VICTORIA, B.C., V8V 3K8
```



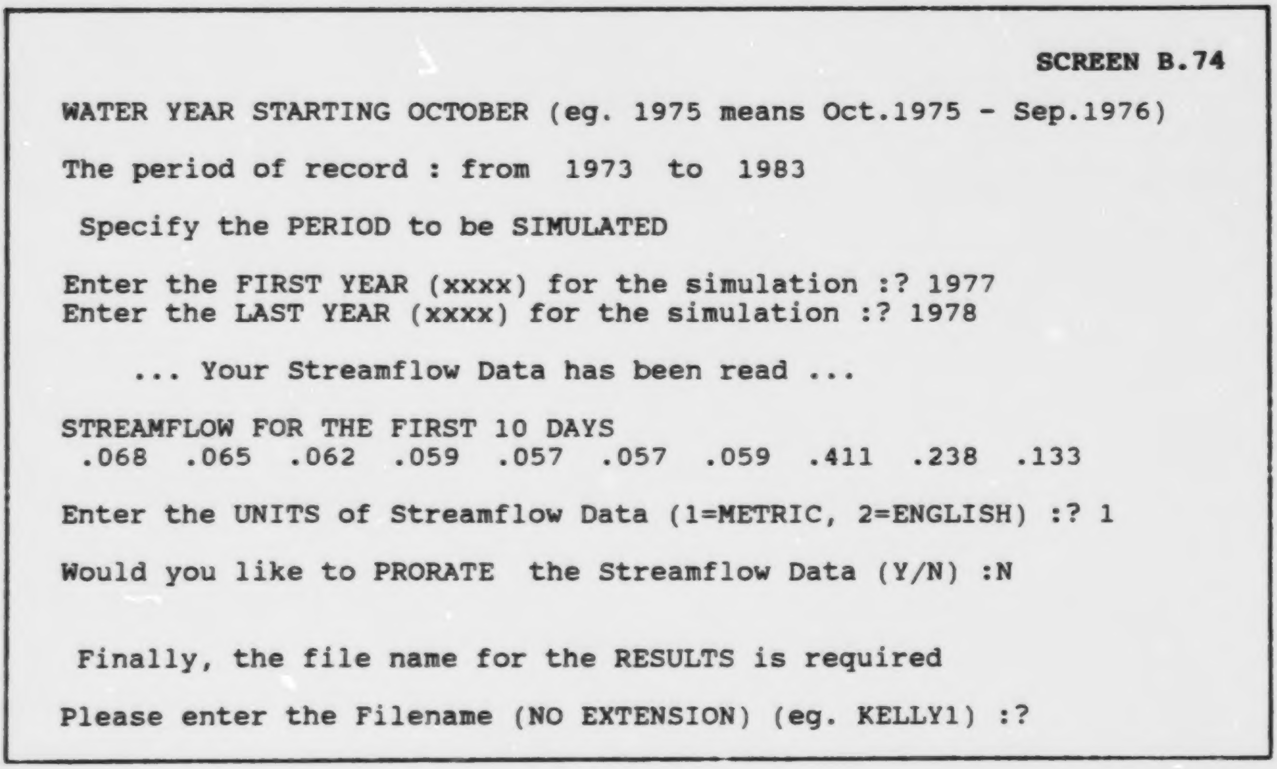
SCREEN B.72

```
( 1 )  CARN.PIN
( 2 )  CARNDEMO.PIN

Is the File that you want on the List (Y/N) :? y

Enter FILE NUMBER for POP INPUT DATA (eg. 1,2,..) :?
```



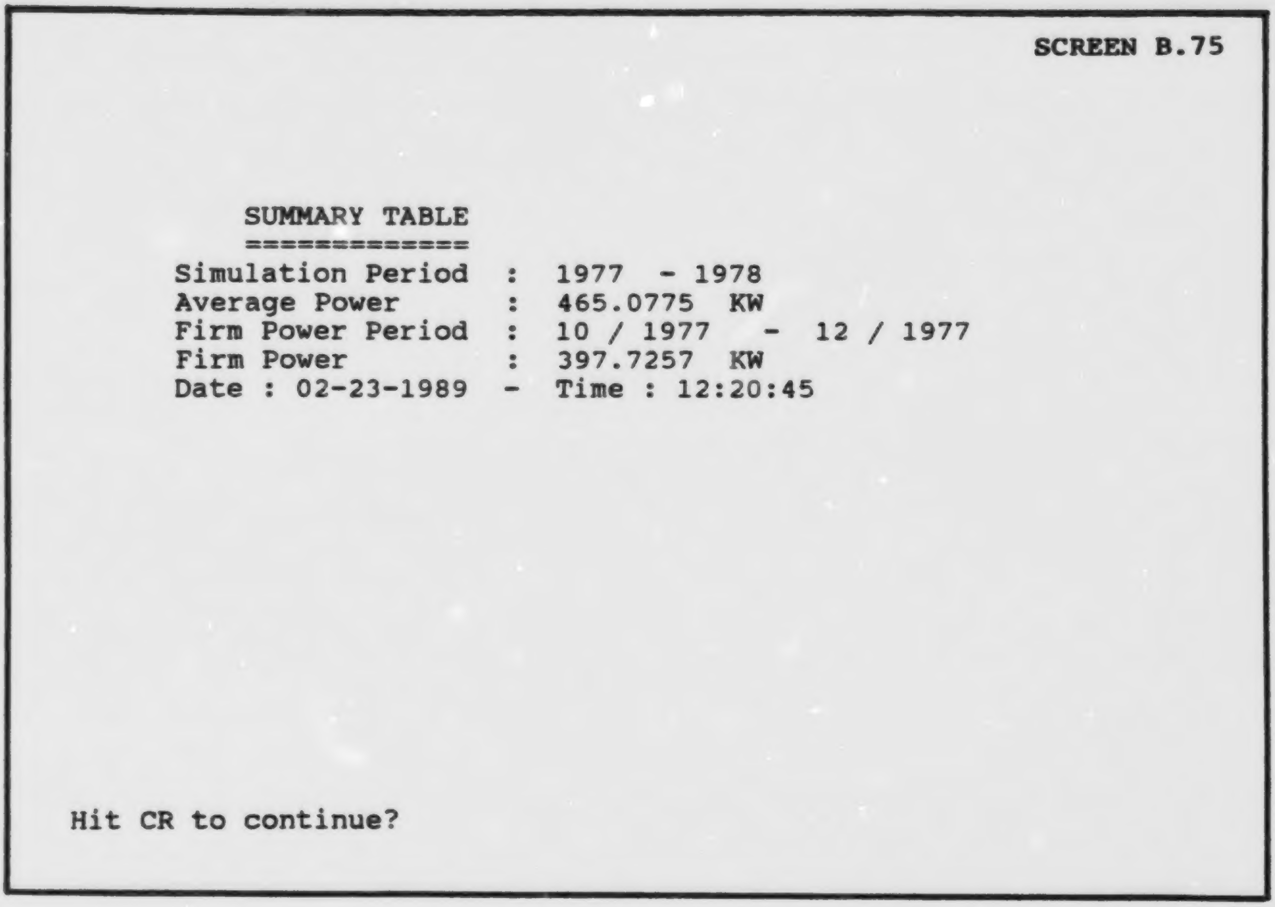
SCREEN B.73

```
( 1 )  CARN2.WSC
( 2 )  CHAP3.WSC
( 3 )  COTT6.WSC
( 4 )  MCKAL5.WSC
( 5 )  PALL1.WSC
( 6 )  PEAR4.WSC
( 7 )  HCT.BCM
( 8 )  DEMO.BCM

Is the File that you want on the List (Y/N) :? y

Enter FILE NUMBER for STREAMFLOW DATA (eg. 1,2,..) :?
```

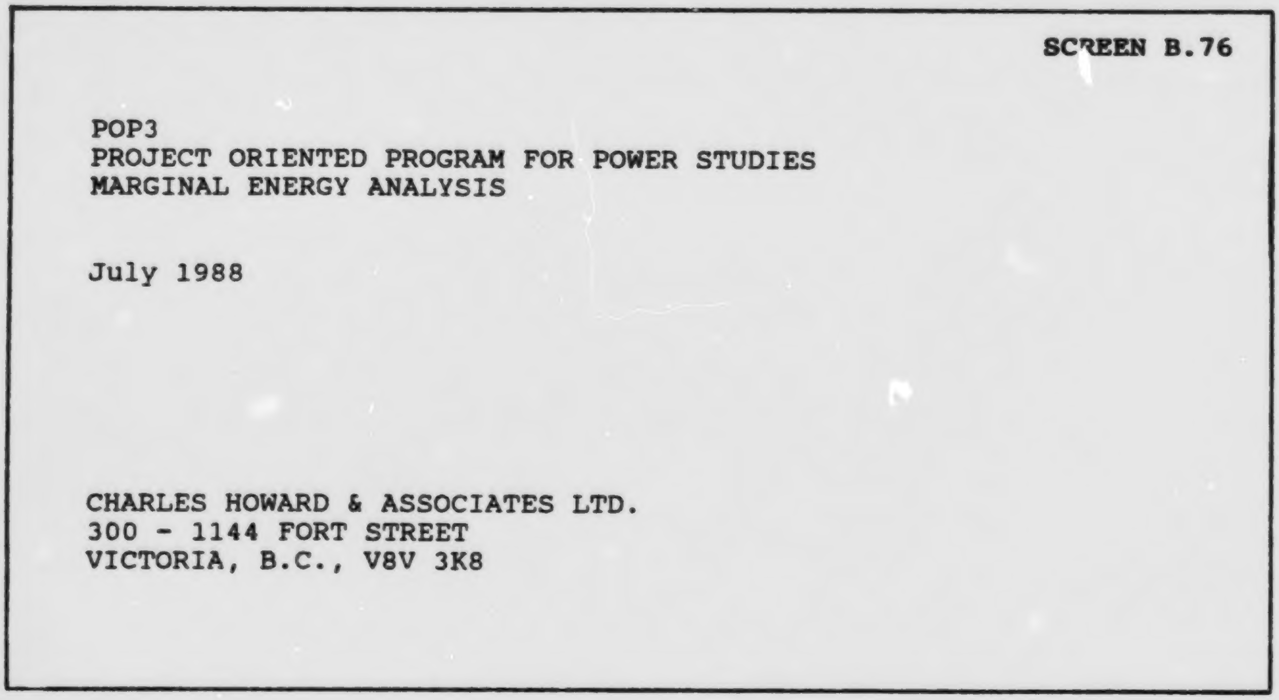


SCREEN B.74

```
WATER YEAR STARTING OCTOBER (eg. 1975 means Oct.1975 - Sep.1976)

The period of record : from  1973  to  1983

 Specify the PERIOD to be SIMULATED

Enter the FIRST YEAR (xxxx) for the simulation :? 1977
Enter the LAST YEAR (xxxx) for the simulation :? 1978

    ... Your Streamflow Data has been read ...

STREAMFLOW FOR THE FIRST 10 DAYS
 .068  .065  .062  .059  .057  .057  .059  .411  .238  .133

Enter the UNITS of Streamflow Data (1=METRIC, 2=ENGLISH) :? 1

Would you like to PRORATE  the Streamflow Data (Y/N) :N


 Finally, the file name for the RESULTS is required

Please enter the Filename (NO EXTENSION) (eg. KELLY1) :?
```

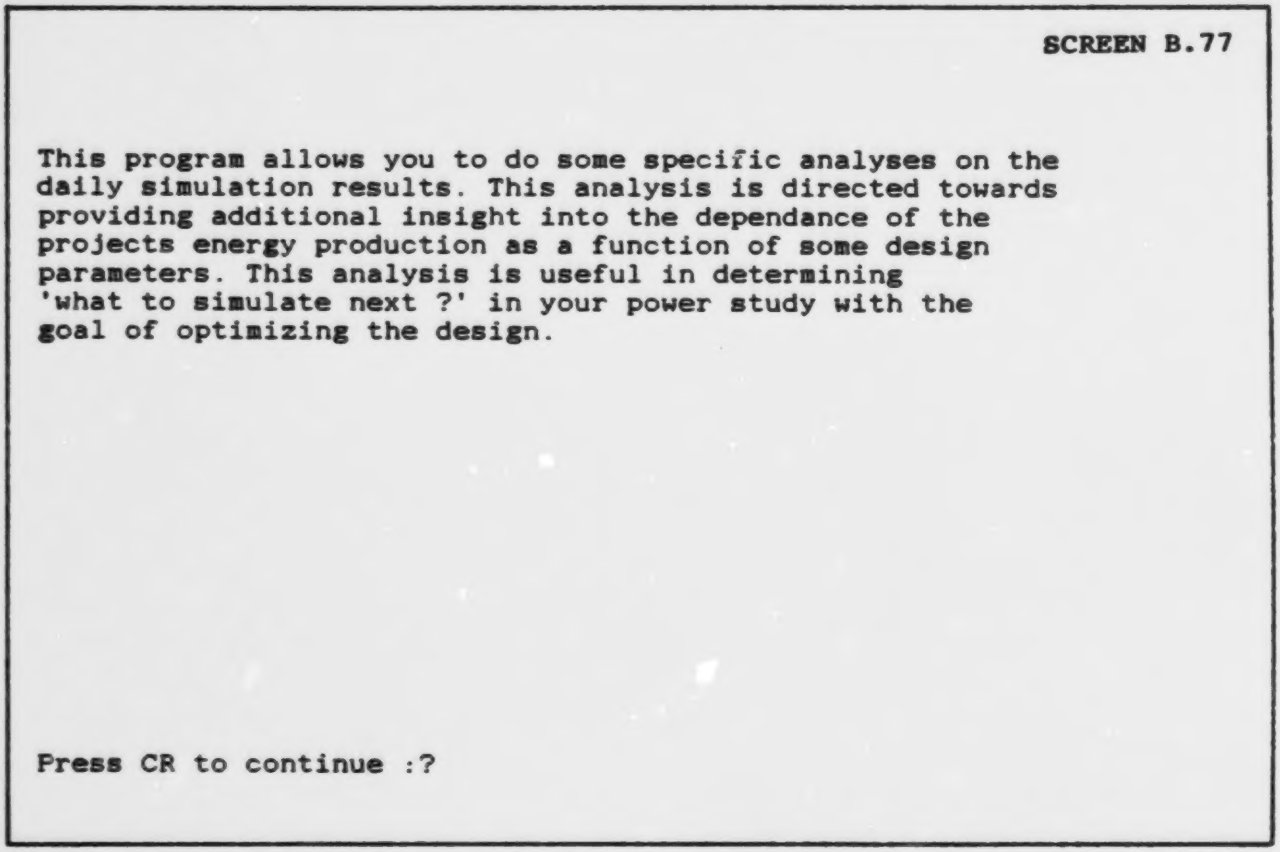


```
                                                   SCREEN B.75



         SUMMARY TABLE
         =============
      Simulation Period  :  1977  - 1978
      Average Power      :  465.0775  KW
      Firm Power Period  :  10 / 1977   -  12 / 1977
      Firm Power         :  397.7257  KW
      Date : 02-23-1989  -  Time : 12:20:45









  Hit CR to continue?
```



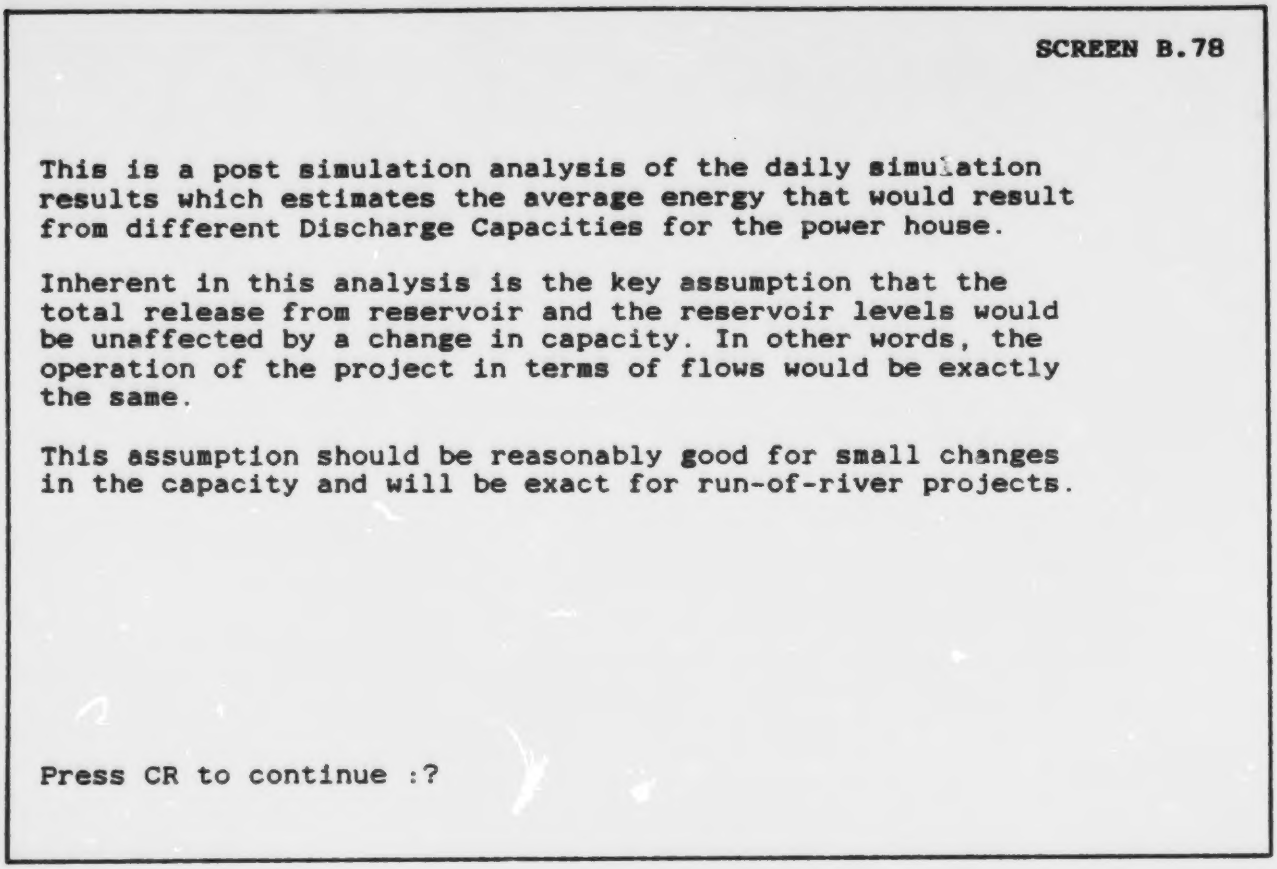
SCREEN B.76

```
POP3
PROJECT ORIENTED PROGRAM FOR POWER STUDIES
MARGINAL ENERGY ANALYSIS


July 1988




CHARLES HOWARD & ASSOCIATES LTD.
300 - 1144 FORT STREET
VICTORIA, B.C., V8V 3K8
```

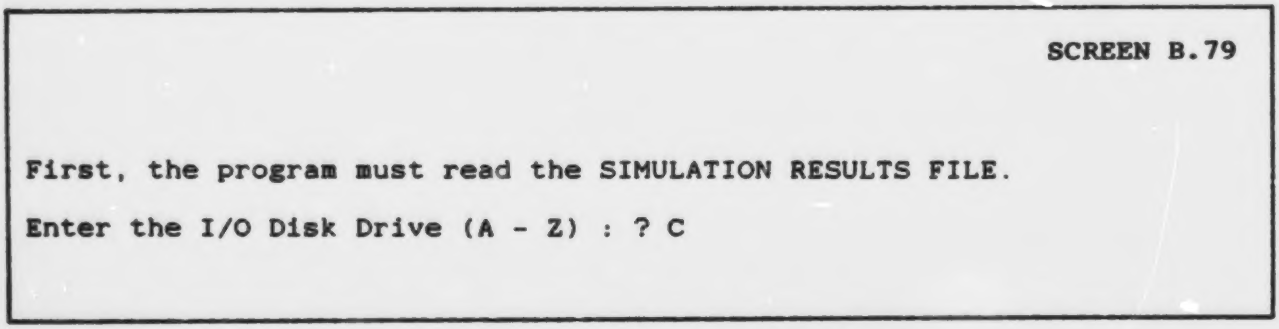


SCREEN B.77

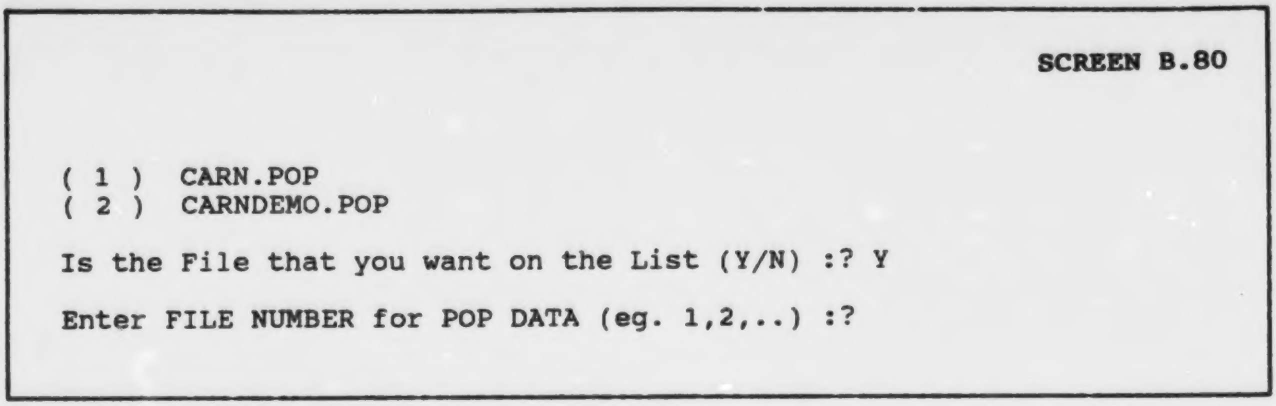
```
This program allows you to do some specific analyses on the
daily simulation results. This analysis is directed towards
providing additional insight into the dependance of the
projects energy production as a function of some design
parameters. This analysis is useful in determining
'what to simulate next ?' in your power study with the
goal of optimizing the design.







Press CR to continue :?
```



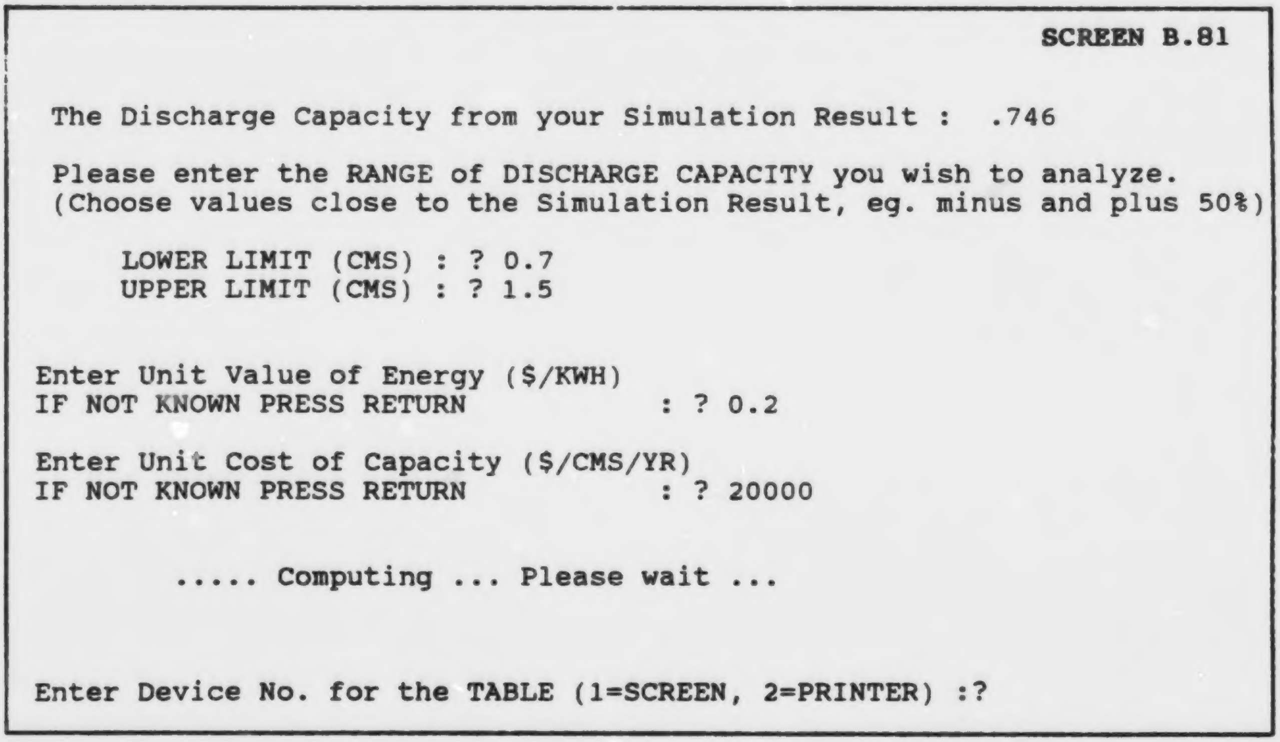
```
                                                    SCREEN B.78


This is a post simulation analysis of the daily simulation
results which estimates the average energy that would result
from different Discharge Capacities for the power house.

Inherent in this analysis is the key assumption that the
total release from reservoir and the reservoir levels would
be unaffected by a change in capacity. In other words, the
operation of the project in terms of flows would be exactly
the same.

This assumption should be reasonably good for small changes
in the capacity and will be exact for run-of-river projects.










Press CR to continue :?
```



```
                                                       SCREEN B.79


First, the program must read the SIMULATION RESULTS FILE.

Enter the I/O Disk Drive (A - Z) : ? C
```

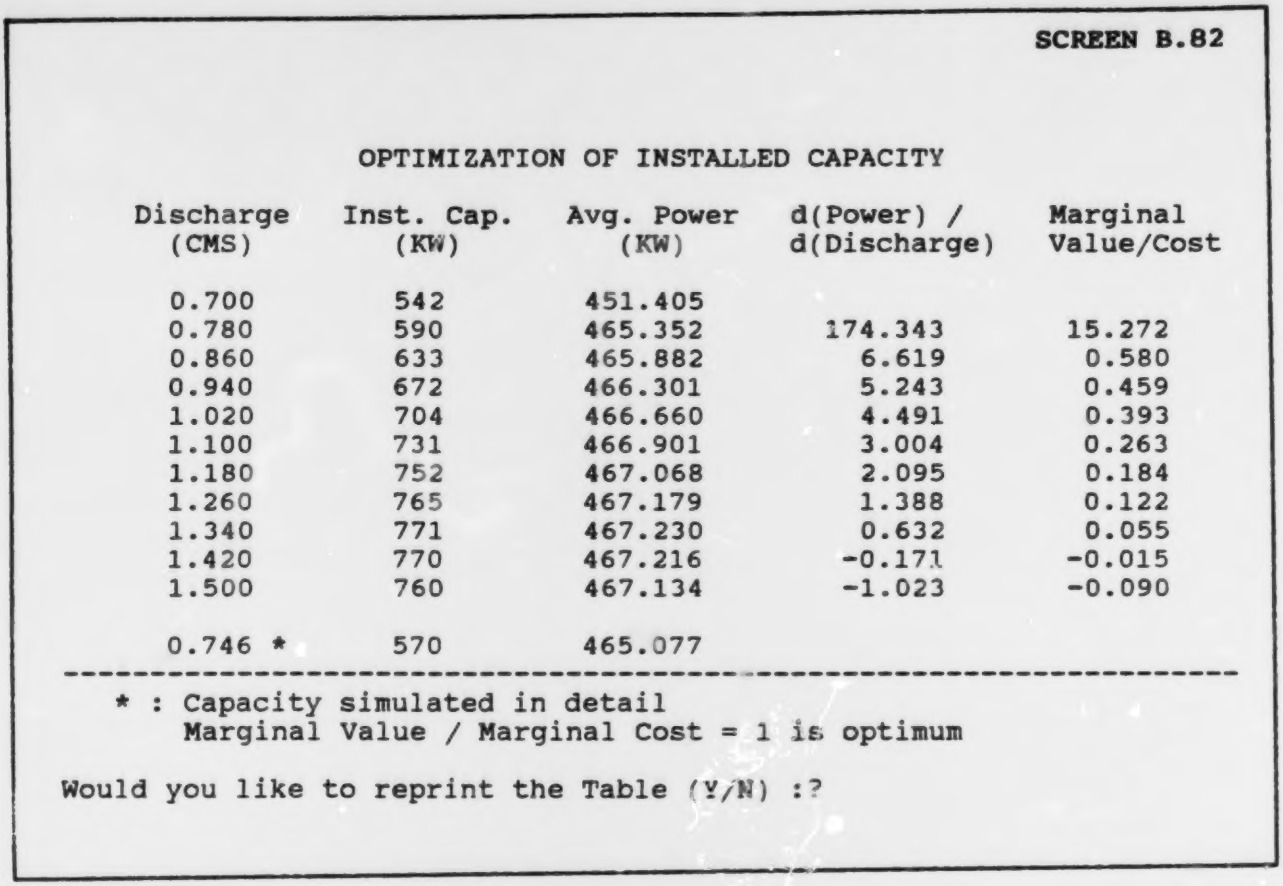


```
                                                                SCREEN B.80


  ( 1 )  CARN.POP
  ( 2 )  CARNDEMO.POP

  Is the File that you want on the List (Y/N) :? Y

  Enter FILE NUMBER for POP DATA (eg. 1,2,..) :?
```



```
                                                                SCREEN B.81

  The Discharge Capacity from your Simulation Result :  .746

  Please enter the RANGE of DISCHARGE CAPACITY you wish to analyze.
  (Choose values close to the Simulation Result, eg. minus and plus 50%)

      LOWER LIMIT (CMS) : ? 0.7
      UPPER LIMIT (CMS) : ? 1.5


 Enter Unit Value of Energy ($/KWH)
 IF NOT KNOWN PRESS RETURN             : ? 0.2

 Enter Unit Cost of Capacity ($/CMS/YR)
 IF NOT KNOWN PRESS RETURN             : ? 20000


        ..... Computing ... Please wait ...



 Enter Device No. for the TABLE (1=SCREEN, 2=PRINTER) :?
```

SCREEN B.82



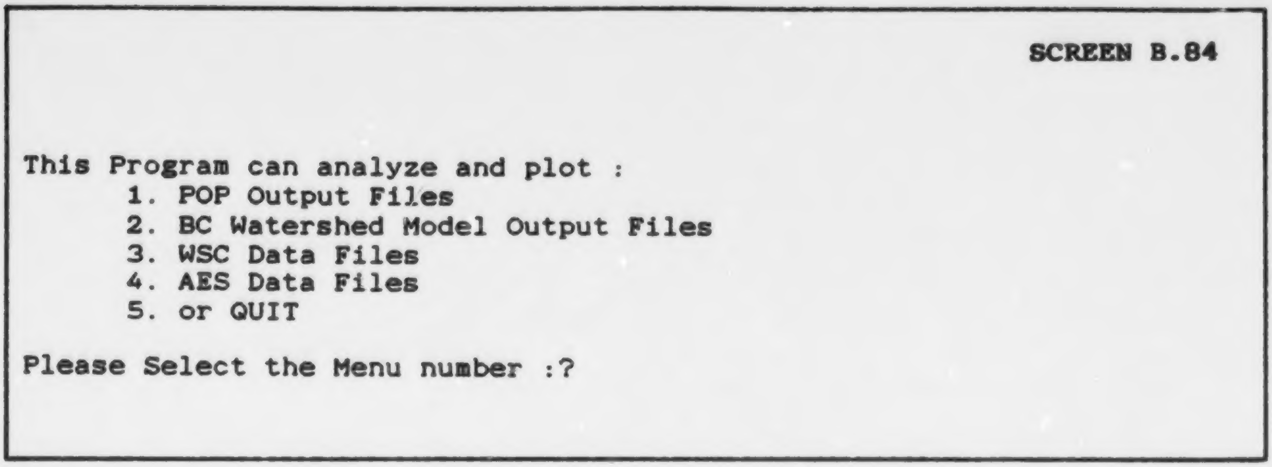
```
                  OPTIMIZATION OF INSTALLED CAPACITY

  Discharge     Inst. Cap.     Avg. Power    d(Power) /       Marginal
    (CMS)          (KW)           (KW)       d(Discharge)     Value/Cost

    0.700          542          451.405
    0.780          590          465.352       174.343         15.272
    0.860          633          465.882         6.619          0.580
    0.940          672          466.301         5.243          0.459
    1.020          704          466.660         4.491          0.393
    1.100          731          466.901         3.004          0.263
    1.180          752          467.068         2.095          0.184
    1.260          765          467.179         1.388          0.122
    1.340          771          467.230         0.632          0.055
    1.420          770          467.216        -0.171         -0.015
    1.500          760          467.134        -1.023         -0.090

    0.746 *        570          465.077
----------------------------------------------------------------------
   * : Capacity simulated in detail
       Marginal Value / Marginal Cost = 1 is optimum

Would you like to reprint the Table (Y/N) :?
```

SCREEN B.83

GAP
A PROGRAM FOR GRAPHICAL AND STATISTICAL TIME SERIES ANALYSIS

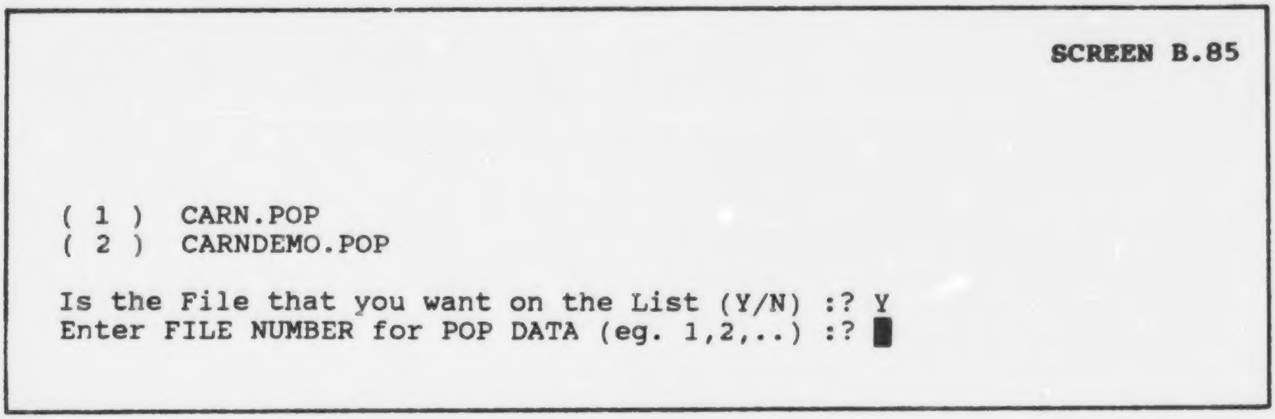
February 1989

CHARLES HOWARD & ASSOCIATES LTD.
300 - 1144 FORT STREET
VICTORIA, B.C., V8V 3K8



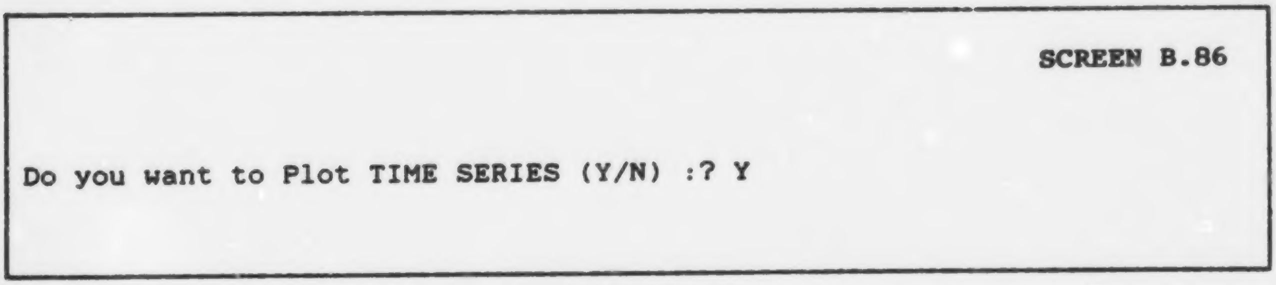
SCREEN B.84

```
This Program can analyze and plot :
      1. POP Output Files
      2. BC Watershed Model Output Files
      3. WSC Data Files
      4. AES Data Files
      5. or QUIT

Please Select the Menu number :?
```



SCREEN B.85

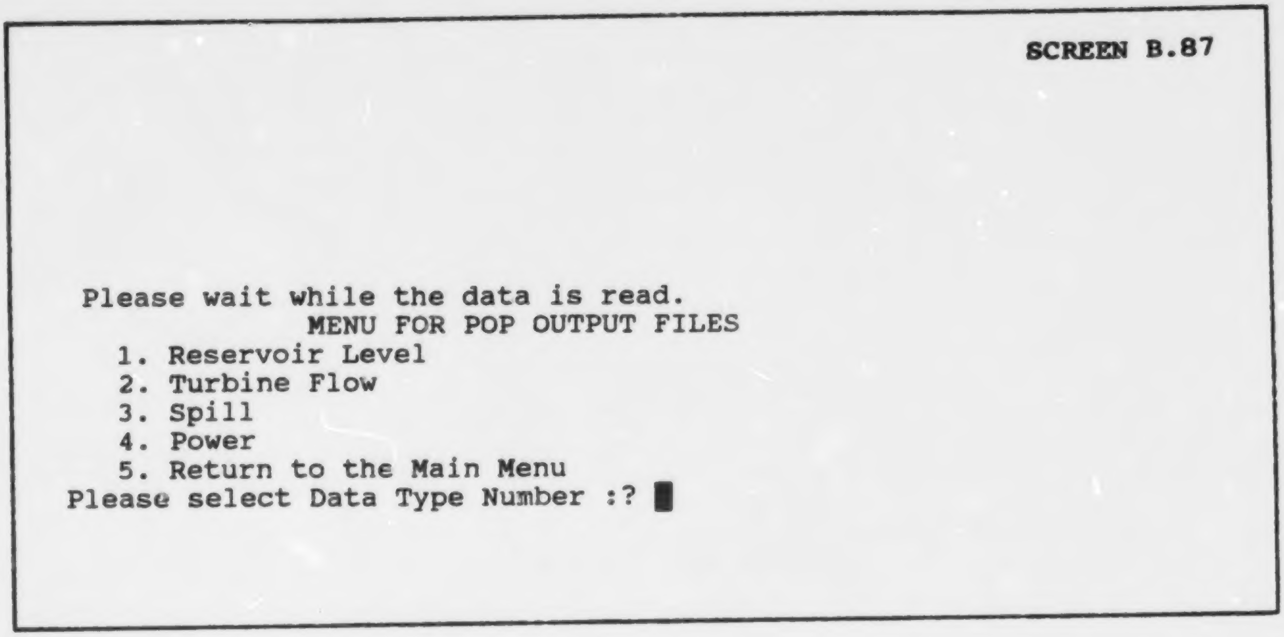
```
  ( 1 )  CARN.POP
  ( 2 )  CARNDEMO.POP

  Is the File that you want on the List (Y/N) :? Y
  Enter FILE NUMBER for POP DATA (eg. 1,2,..) :?
```



SCREEN B.86

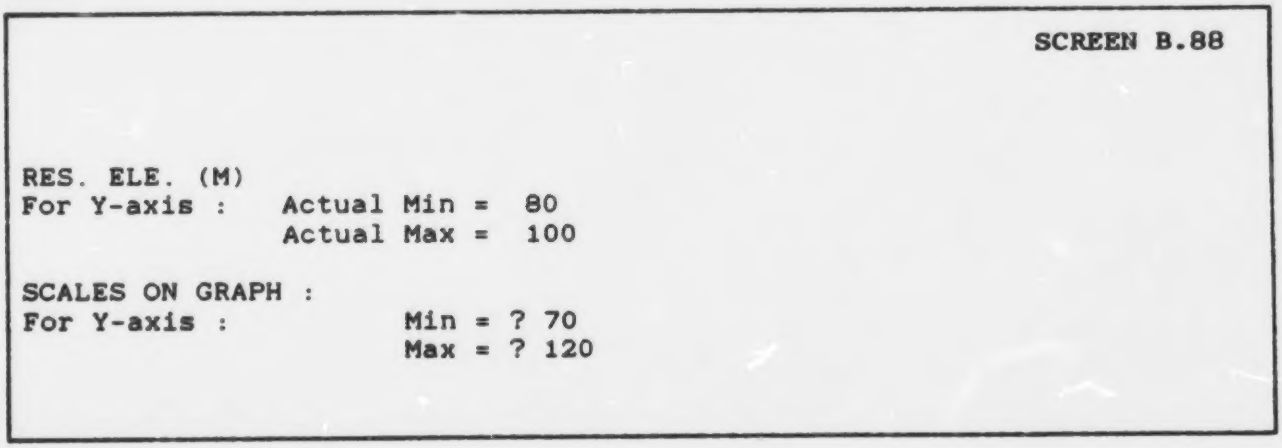
```
Do you want to Plot TIME SERIES (Y/N) :? Y
```

SCREEN B.87



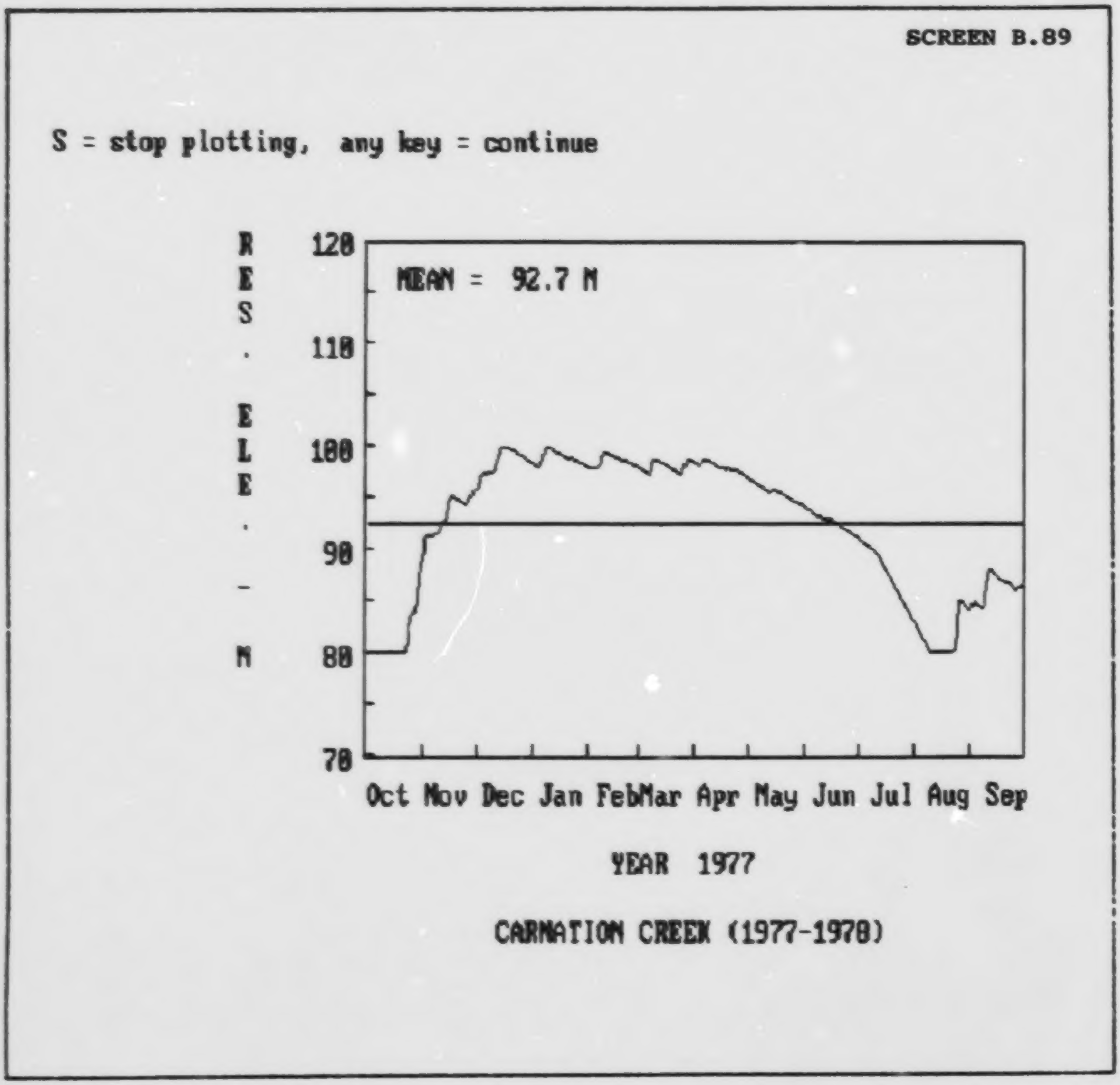
```
Please wait while the data is read.
             MENU FOR POP OUTPUT FILES
  1. Reservoir Level
  2. Turbine Flow
  3. Spill
  4. Power
  5. Return to the Main Menu
Please select Data Type Number :? █
```

SCREEN B.88



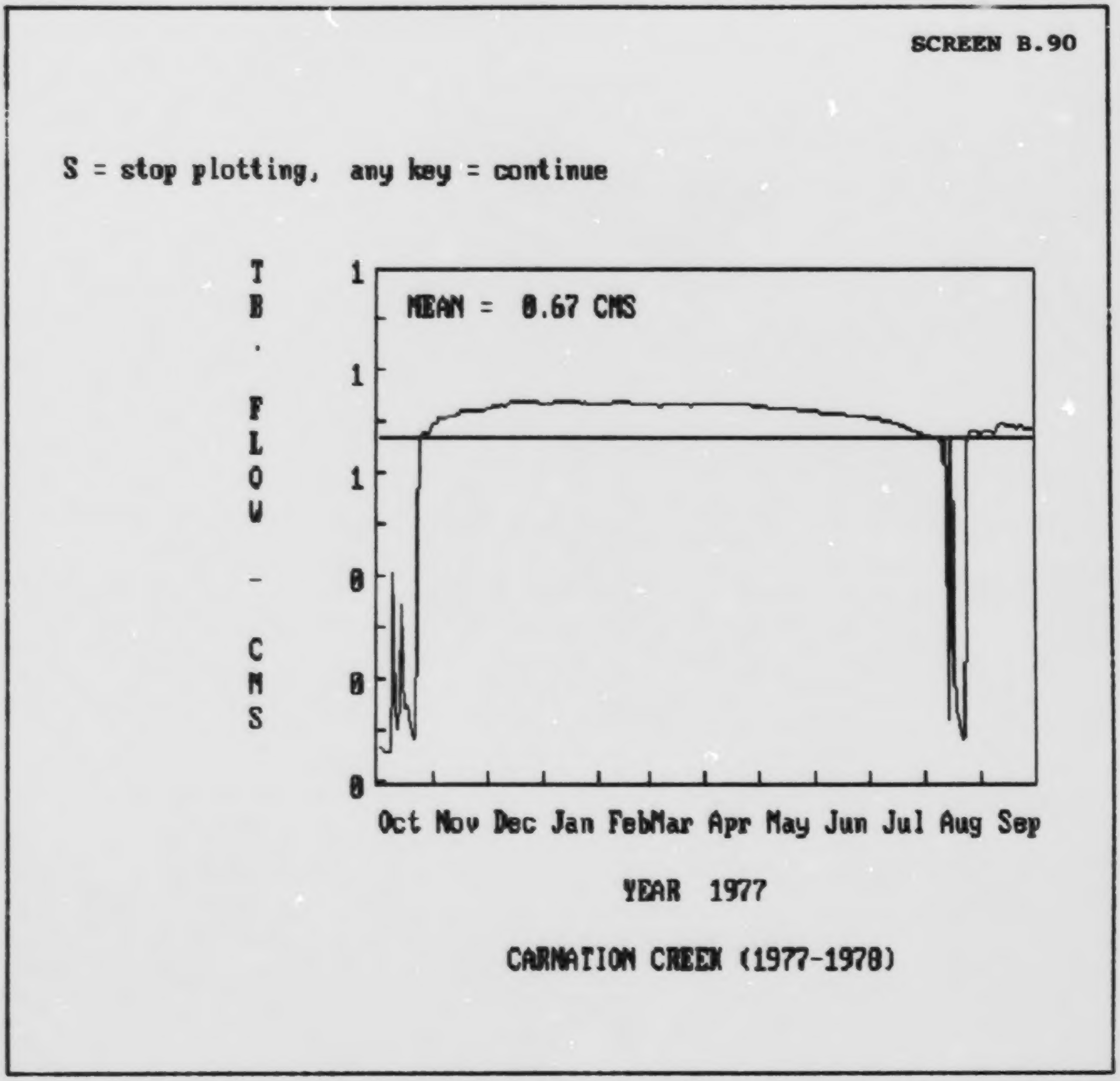
```
RES. ELE. (M)
For Y-axis :   Actual Min =  80
               Actual Max =  100

SCALES ON GRAPH :
For Y-axis :          Min = ? 70
                      Max = ? 120
```

SCREEN B.89



S = stop plotting, any key = continue

RES. ELE. - M
120
110
100
90
80
70
MEAN = 92.7 M
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
YEAR 1977
CARNATION CREEK (1977-1978)



SCREEN B.90

S = stop plotting, any key = continue

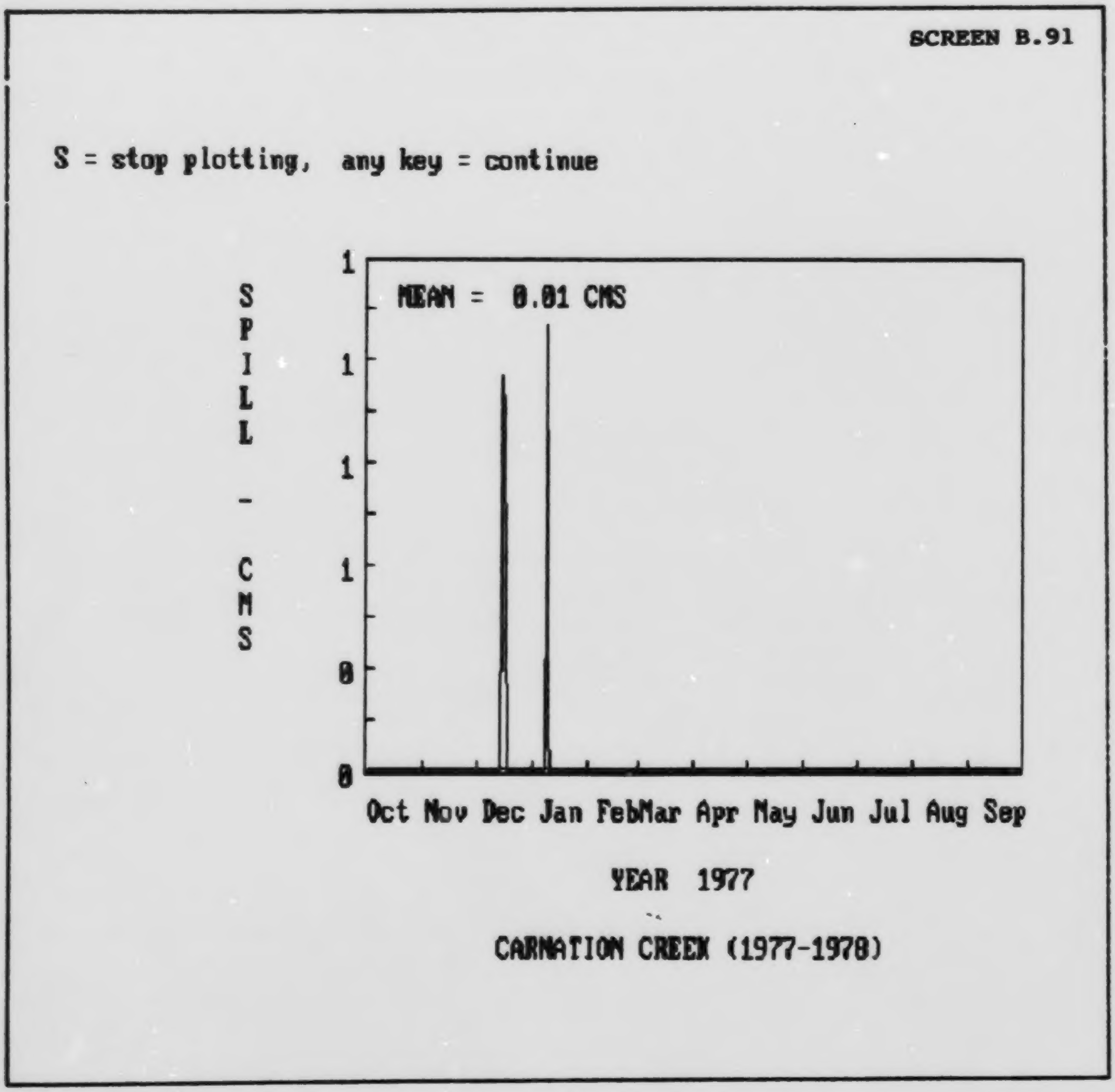
MEAN = 0.67 CMS

TB. FLOW - CMS
1
1
1
0
0
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

YEAR 1977

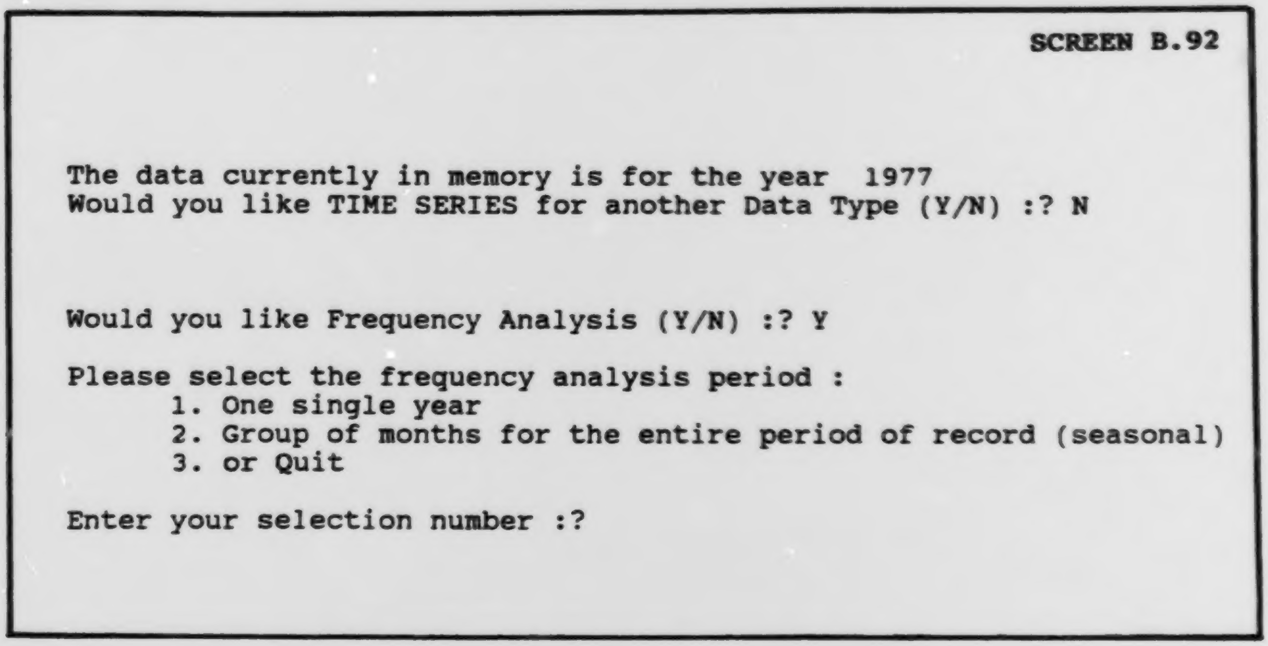
CARNATION CREEK (1977-1978)

SCREEN B.91



S = stop plotting, any key = continue

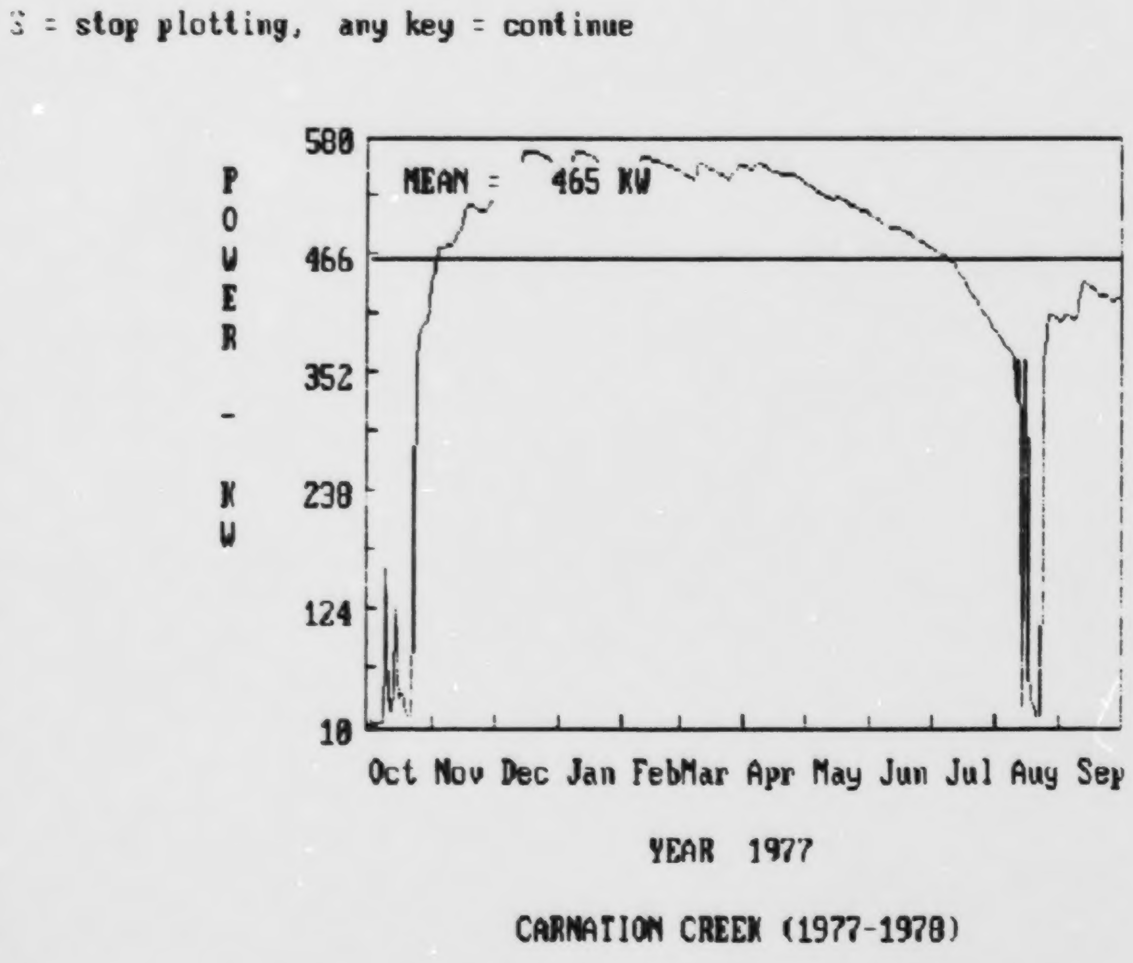
SPILL - CMS
1
1
1
1
1
0
0
MEAN = 0.01 CMS
Oct Nov Dec Jan FebMar Apr May Jun Jul Aug Sep
YEAR 1977
CARNATION CREEK (1977-1978)



SCREEN B.92

```
The data currently in memory is for the year  1977
Would you like TIME SERIES for another Data Type (Y/N) :? N



Would you like Frequency Analysis (Y/N) :? Y

Please select the frequency analysis period :
      1. One single year
      2. Group of months for the entire period of record (seasonal)
      3. or Quit

Enter your selection number :?
```

SCREEN B.93

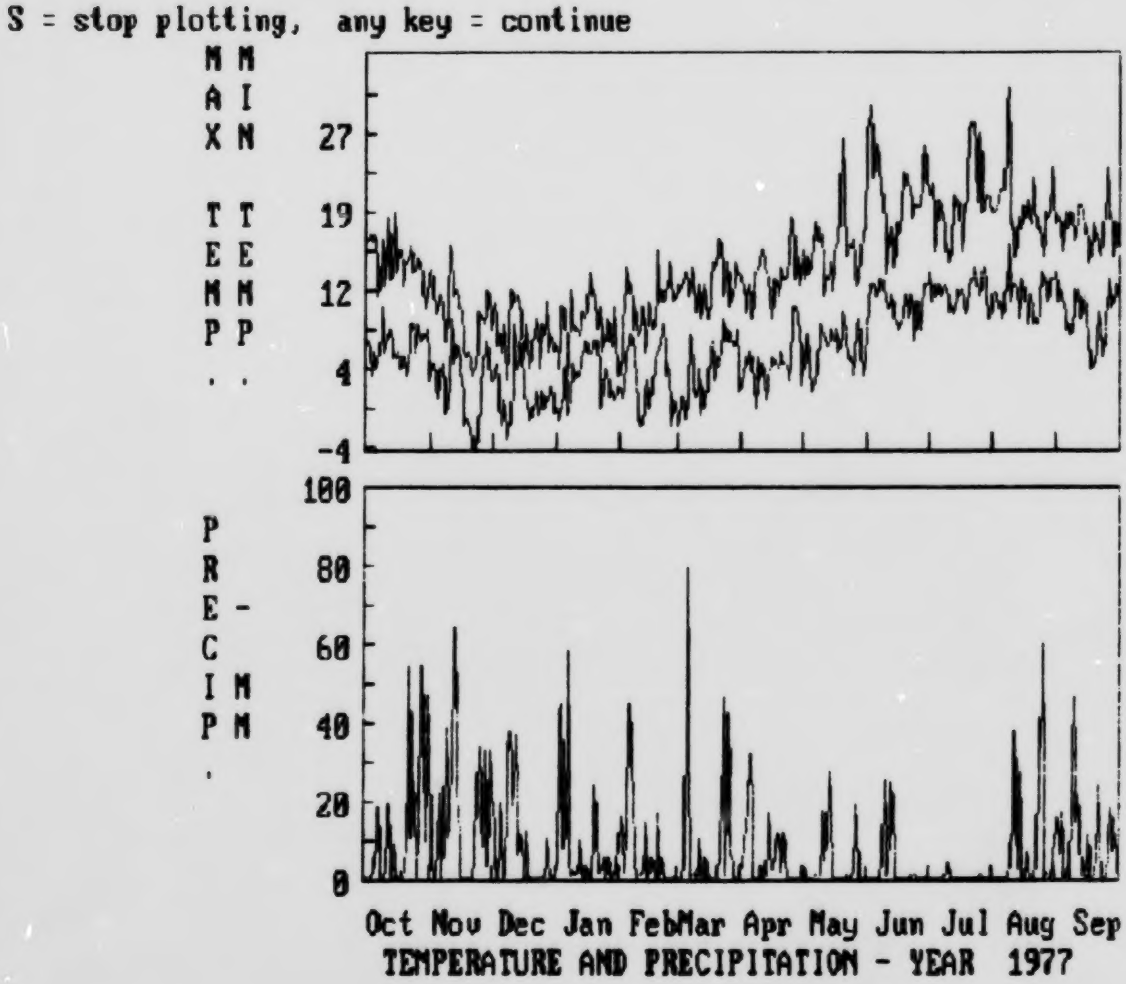


S = stop plotting, any key = continue

MEAN = 465 KW
POWER - KW
580
466
352
238
124
10
Oct Nov Dec Jan FebMar Apr May Jun Jul Aug Sep
YEAR 1977
CARNATION CREEK (1977-1978)

```
                                                            SCREEN B.94


   FOR GRAPH 1

   MAX TEMP. & MIN TEMP.
   For upper Y-axis :   Actual Min = -3.9
                        Actual Max =  31.7

   SCALES ON GRAPH 1 :
   For upper Y-axis :         Min = ? -4
                              Max = ? 35


   FOR GRAPH 2

   PRECIP. &  - MM
   For lower Y-axis :   Actual Min =  0
                        Actual Max =  80

   SCALES ON GRAPH 2 :
   For lower Y-axis :         Min = ? 0
                              Max = ? 100
```

SCREEN B.95



```
S = stop plotting,  any key = continue
```

SCREEN B.96

```
number of records = 70

( 1 )  DEMO.BCM
( 2 )  COCH.BCM

Is the File that you want on the List (Y/N) :? Y
Enter FILE NUMBER for BC MODEL FILES (eg. 1,2,..) :? 2

Do you want to Plot TIME SERIES (Y/N) :?
```

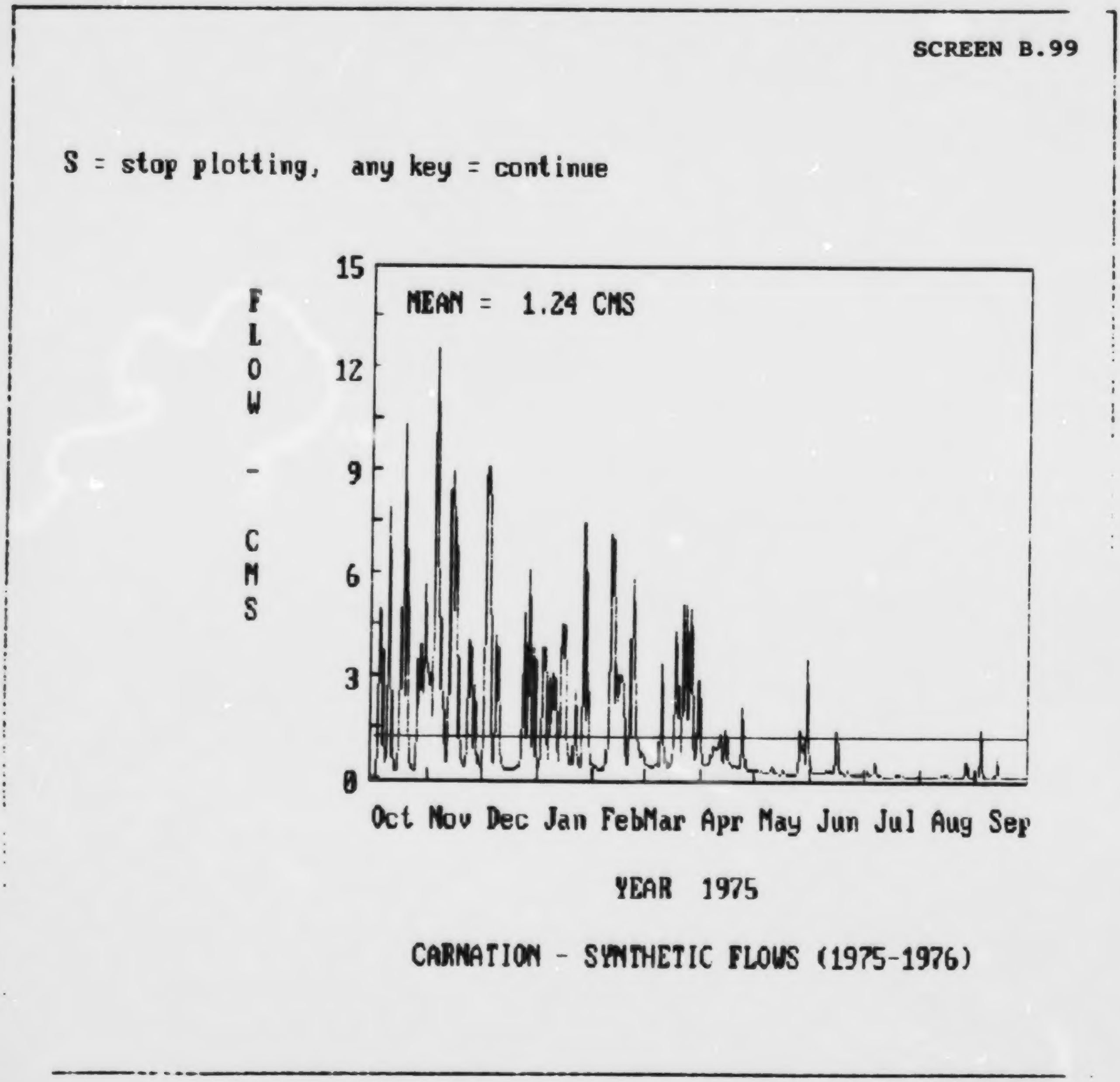
SCREEN B.97

```
 WATER YEAR STARTING OCTOBER (eg. 1975 means Oct.1975 - Sep.1976)

 The first year of this record : 1975 . The last year : 1976

 Enter the WATER YEAR (xxxx) you want to read data in :? 1975

 Data of the Water Year 1975  are loading... Please wait
```

SCREEN B.98

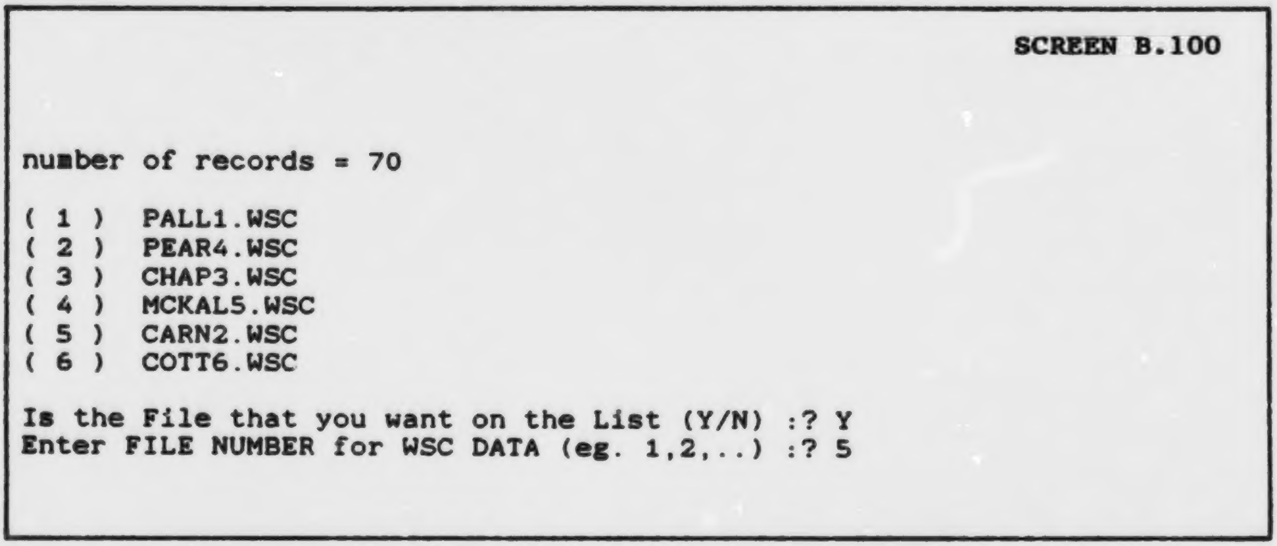
```
FLOW (CMS)
For Y-axis :   Actual Min =  .055
               Actual Max =  .451

SCALES ON GRAPH :
For Y-axis :          Min = ? 0
                      Max = ? 1
```

SCREEN B.99



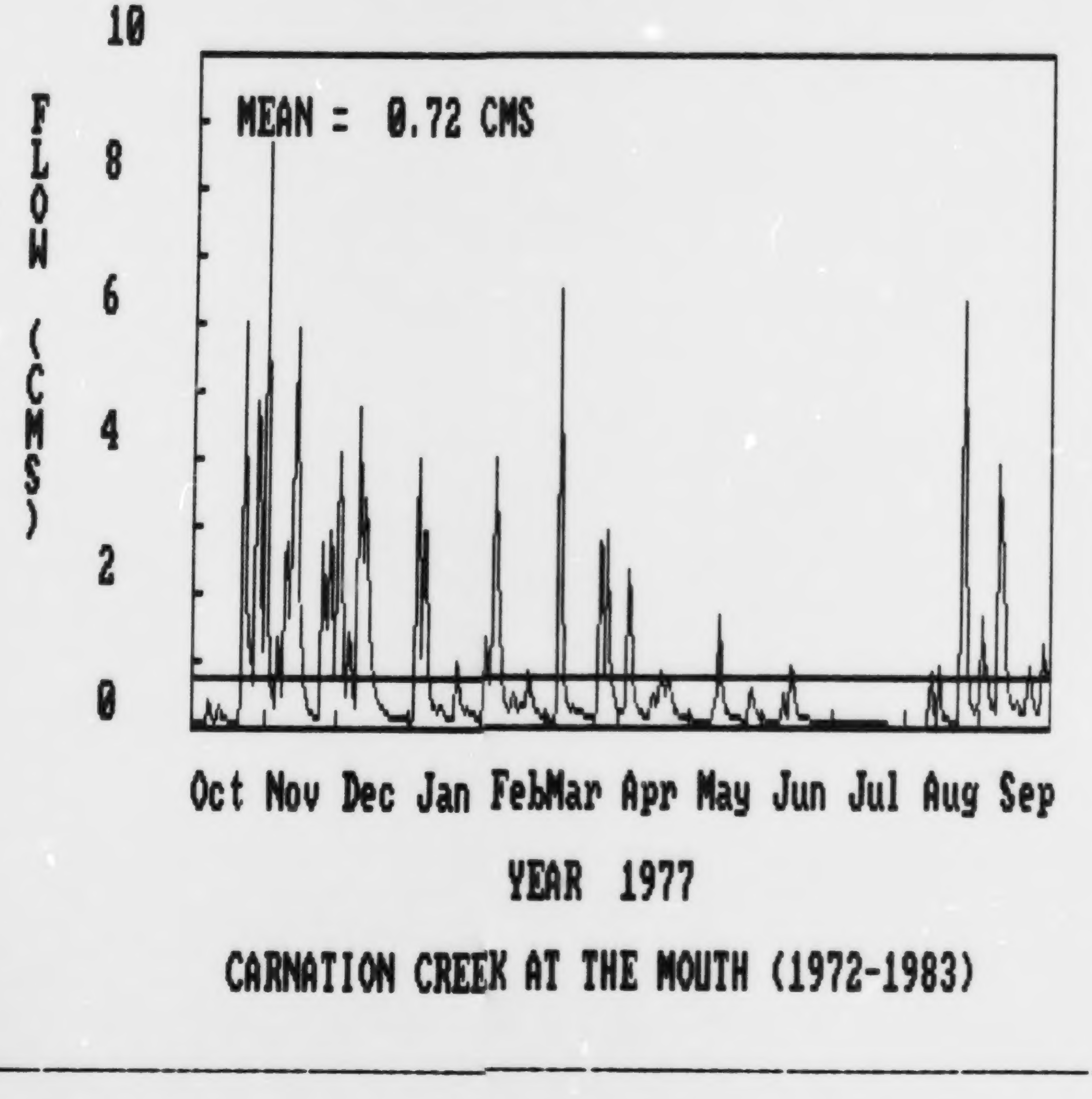
```
S = stop plotting,  any key = continue
```

MEAN = 1.24 CMS
FLOW - CMS
15
12
9
6
3
0
Oct Nov Dec Jan FebMar Apr May Jun Jul Aug Sep
YEAR 1975
CARNATION - SYNTHETIC FLOWS (1975-1976)



```
                                                          SCREEN B.100


number of records = 70

( 1 )  PALL1.WSC
( 2 )  PEAR4.WSC
( 3 )  CHAP3.WSC
( 4 )  MCKAL5.WSC
( 5 )  CARN2.WSC
( 6 )  COTT6.WSC

Is the File that you want on the List (Y/N) :? Y
Enter FILE NUMBER for WSC DATA (eg. 1,2,..) :? 5
```

SCREEN B.101



YEAR 1977

CARNATION CREEK AT THE MOUTH (1972-1983)

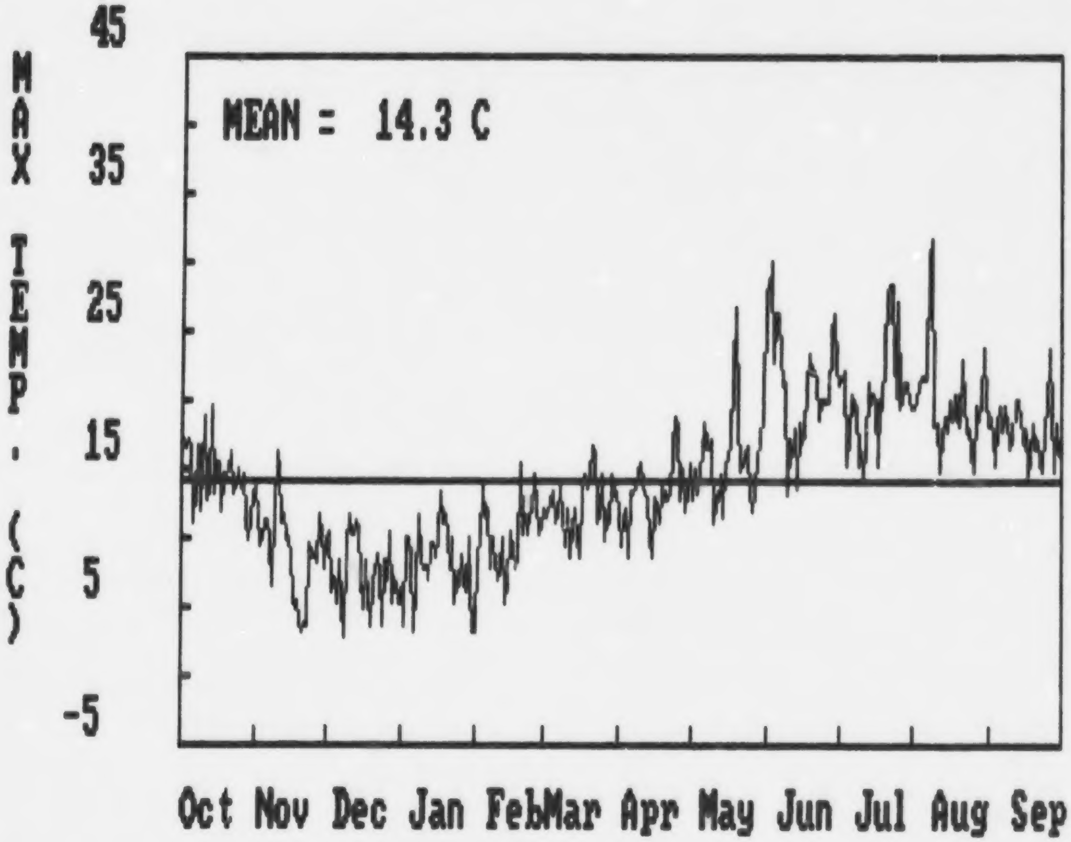
SCREEN B.102

```
number of records = 70

( 1 )  ATLIN6.AES
( 2 )  GIBS3.AES
( 3 )  CARN2.AES
( 4 )  BARK5.AES
( 5 )  MCCUL4.AES
( 6 )  TASU1.AES

Is the File that you want on the List (Y/N) :? Y
Enter FILE NUMBER for AES DATA (eg. 1,2,..) :? 3
```

SCREEN B.103

```
What Data you want to Plot or Analyze:
    1.  Max. Temperature
    2.  Min. Temperature
    3.  Precipitation
    4.  All of them
Please select Data Number :?
```

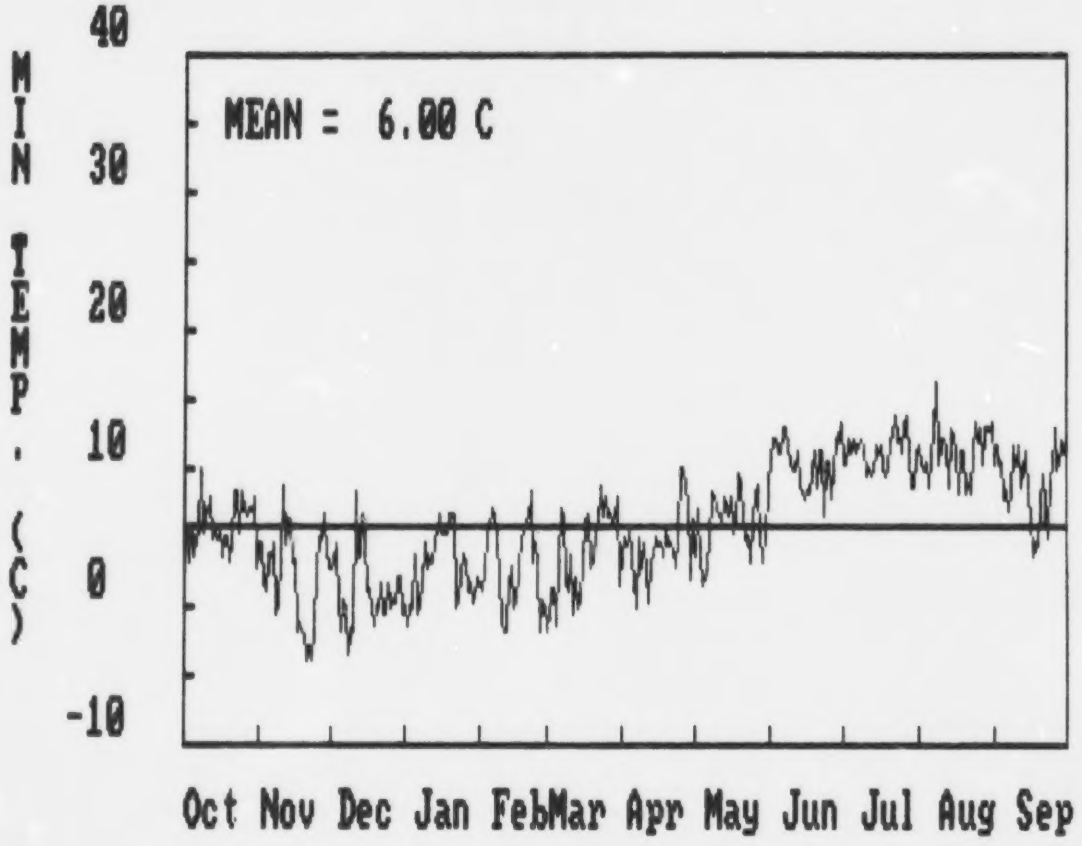
SCREEN B.104



YEAR 1977

CARNATION (1973-1983)

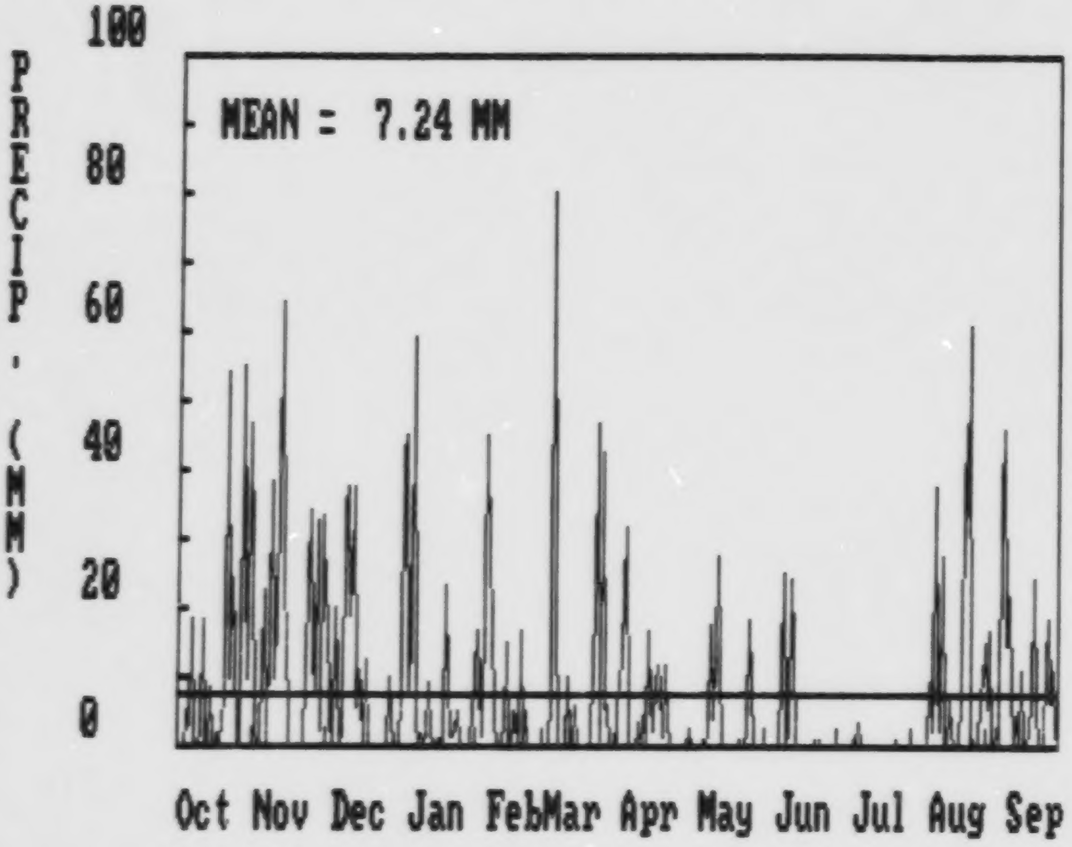
SCREEN B.105



YEAR 1977

CARNATION (1973-1983)

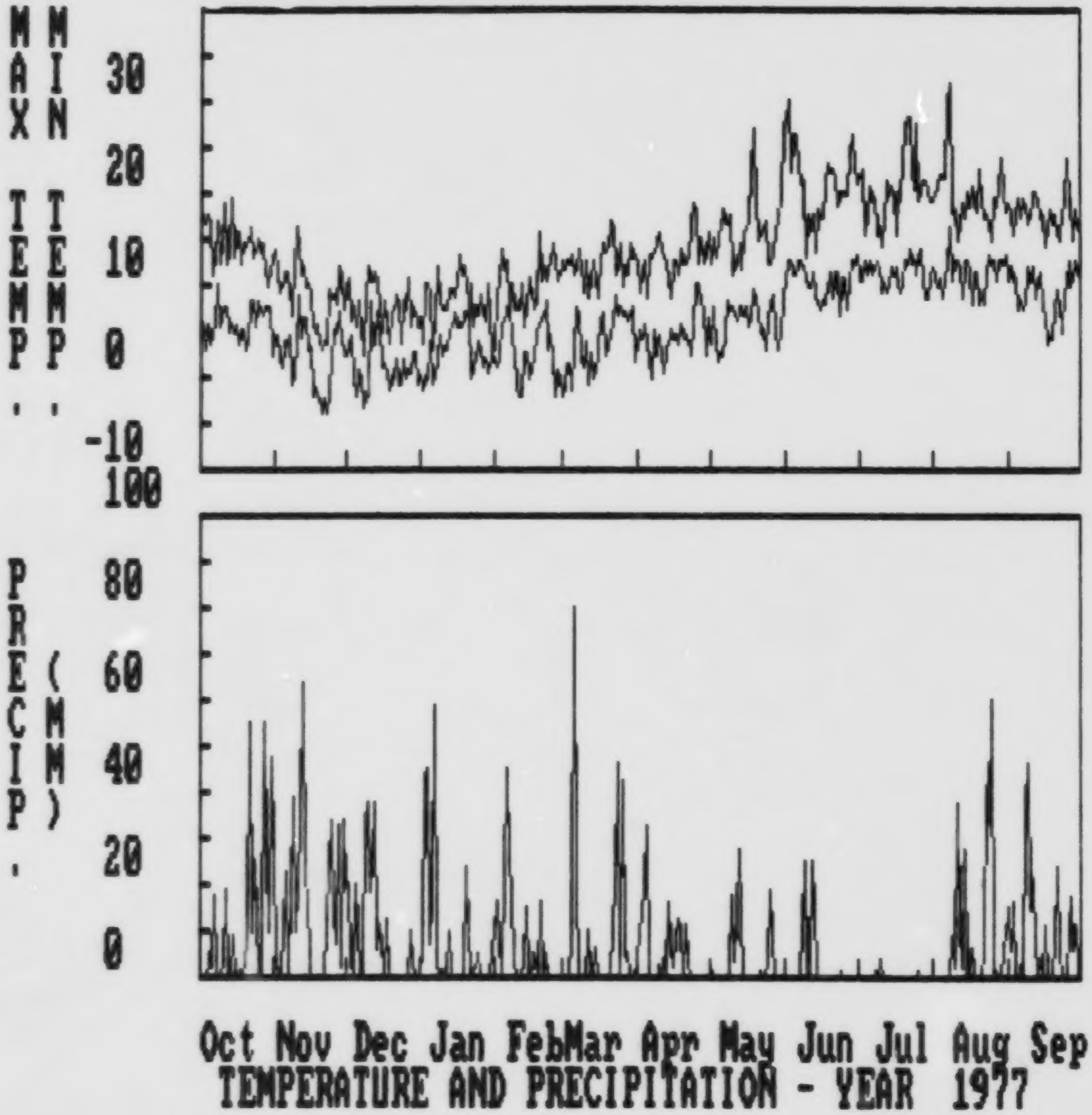
SCREEN B.106



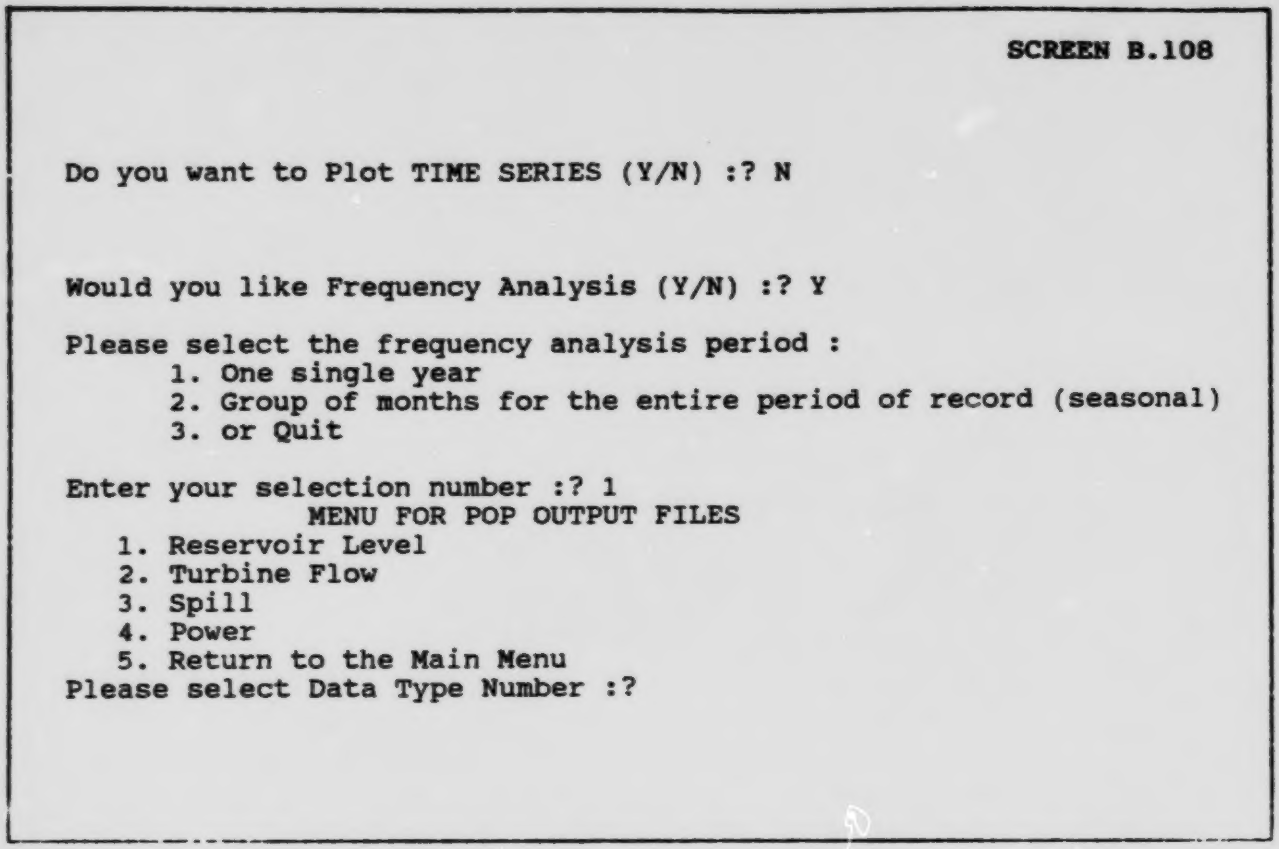
YEAR 1977

CARNATION (1973-1983)

SCREEN B.107

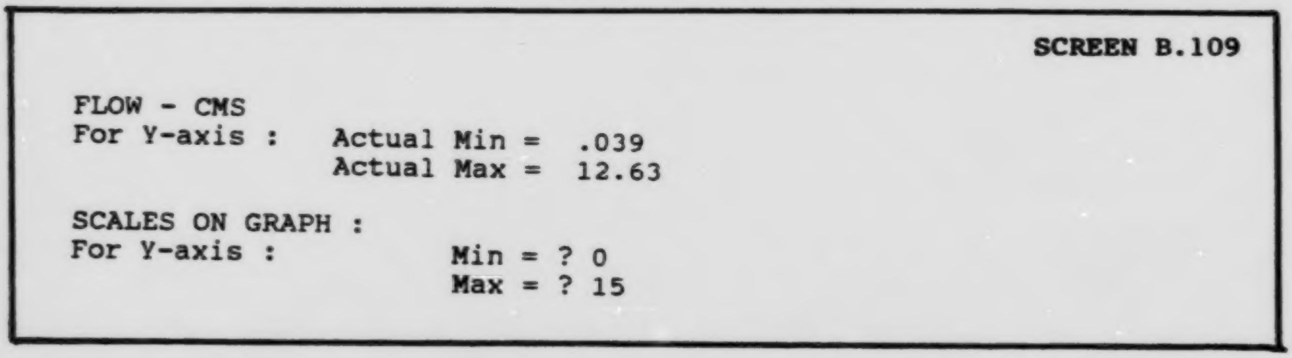


TEMPERATURE AND PRECIPITATION - YEAR 1977



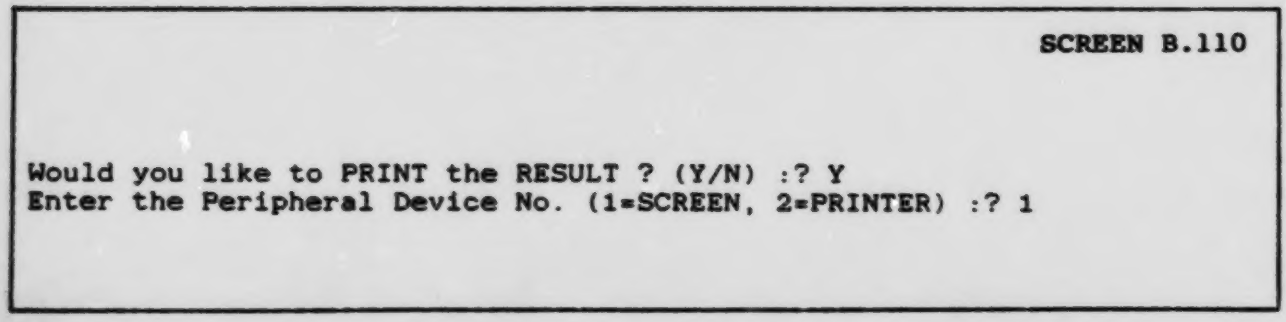
SCREEN B.108

```
Do you want to Plot TIME SERIES (Y/N) :? N



Would you like Frequency Analysis (Y/N) :? Y

Please select the frequency analysis period :
      1. One single year
      2. Group of months for the entire period of record (seasonal)
      3. or Quit

Enter your selection number :? 1
                 MENU FOR POP OUTPUT FILES
   1. Reservoir Level
   2. Turbine Flow
   3. Spill
   4. Power
   5. Return to the Main Menu
Please select Data Type Number :?
```



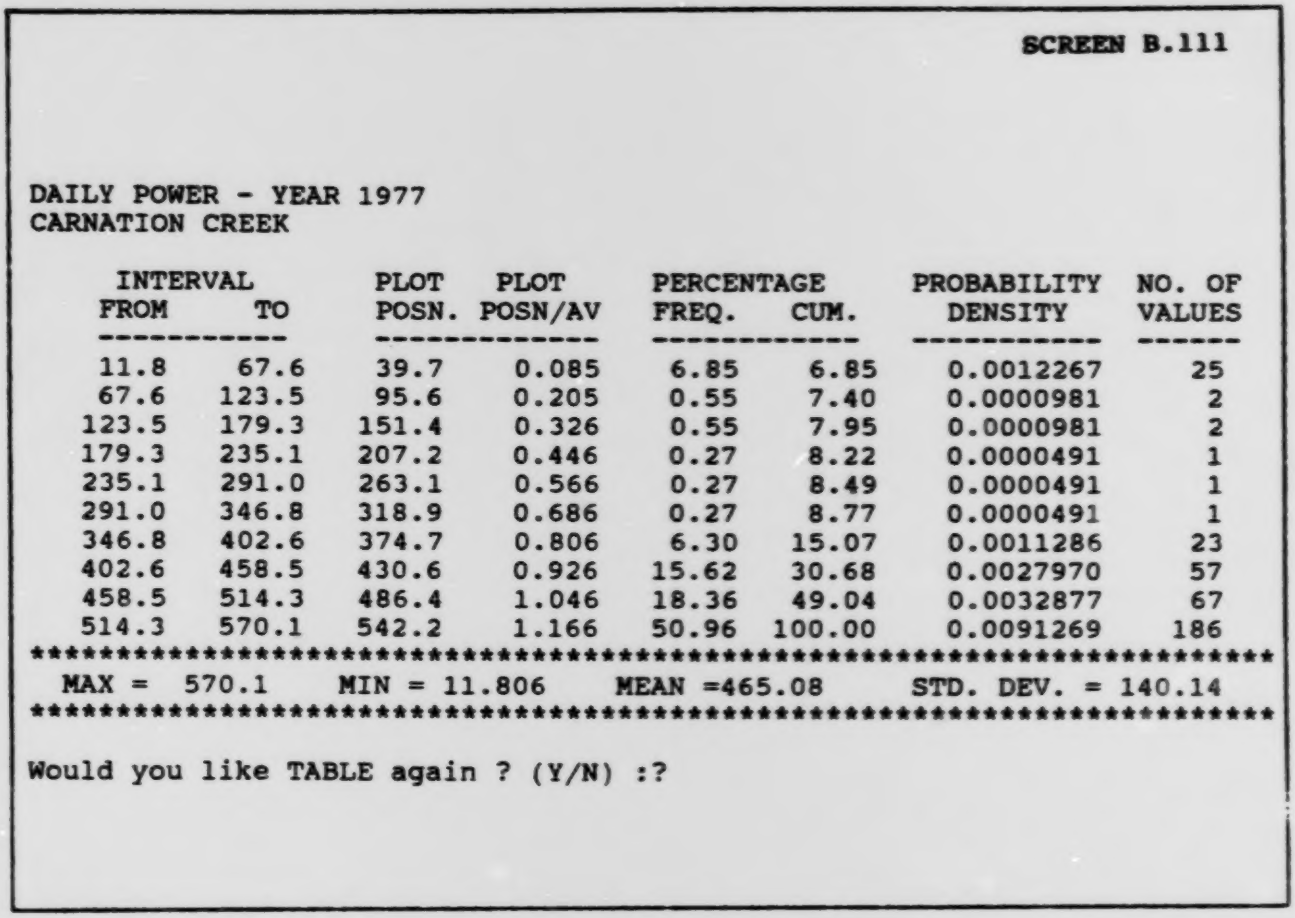
SCREEN B.109

```
FLOW - CMS
For Y-axis :    Actual Min =  .039
                Actual Max =  12.63

SCALES ON GRAPH :
For Y-axis :             Min = ? 0
                         Max = ? 15
```

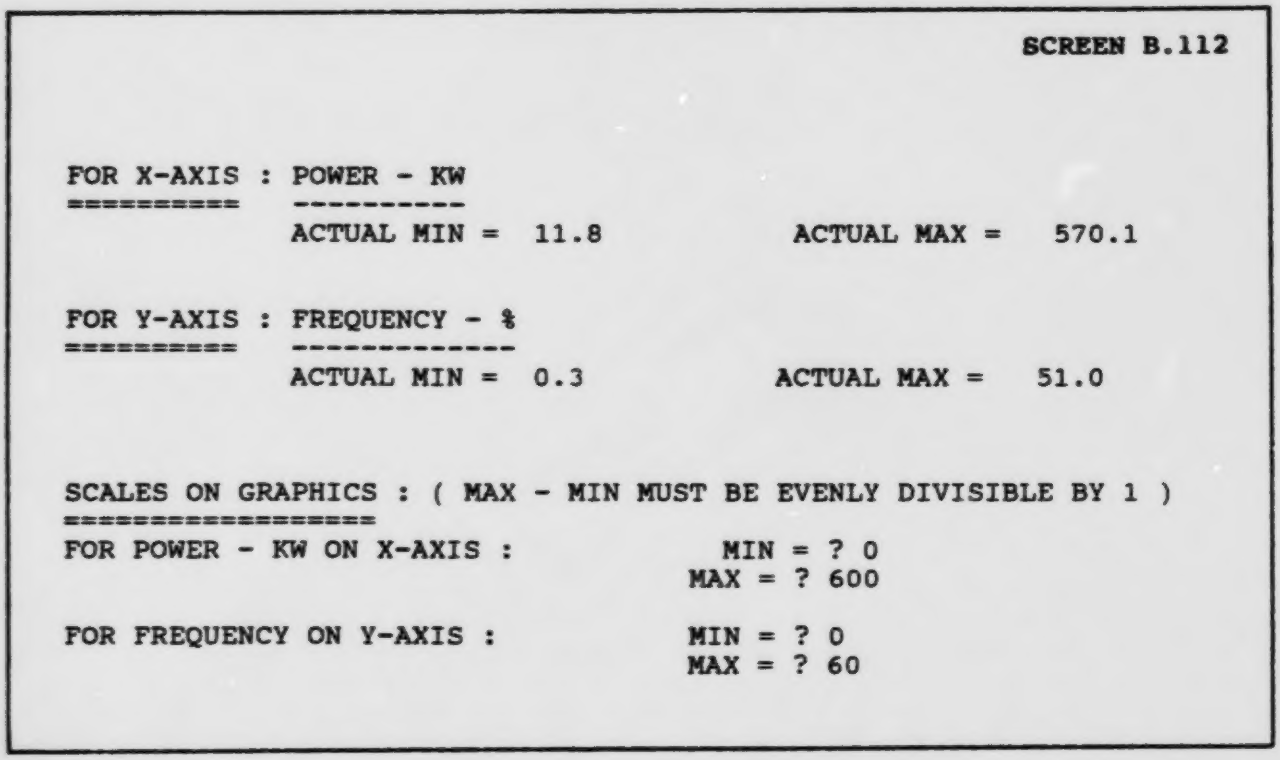


SCREEN B.110

```
Would you like to PRINT the RESULT ? (Y/N) :? Y
Enter the Peripheral Device No. (1=SCREEN, 2=PRINTER) :? 1
```

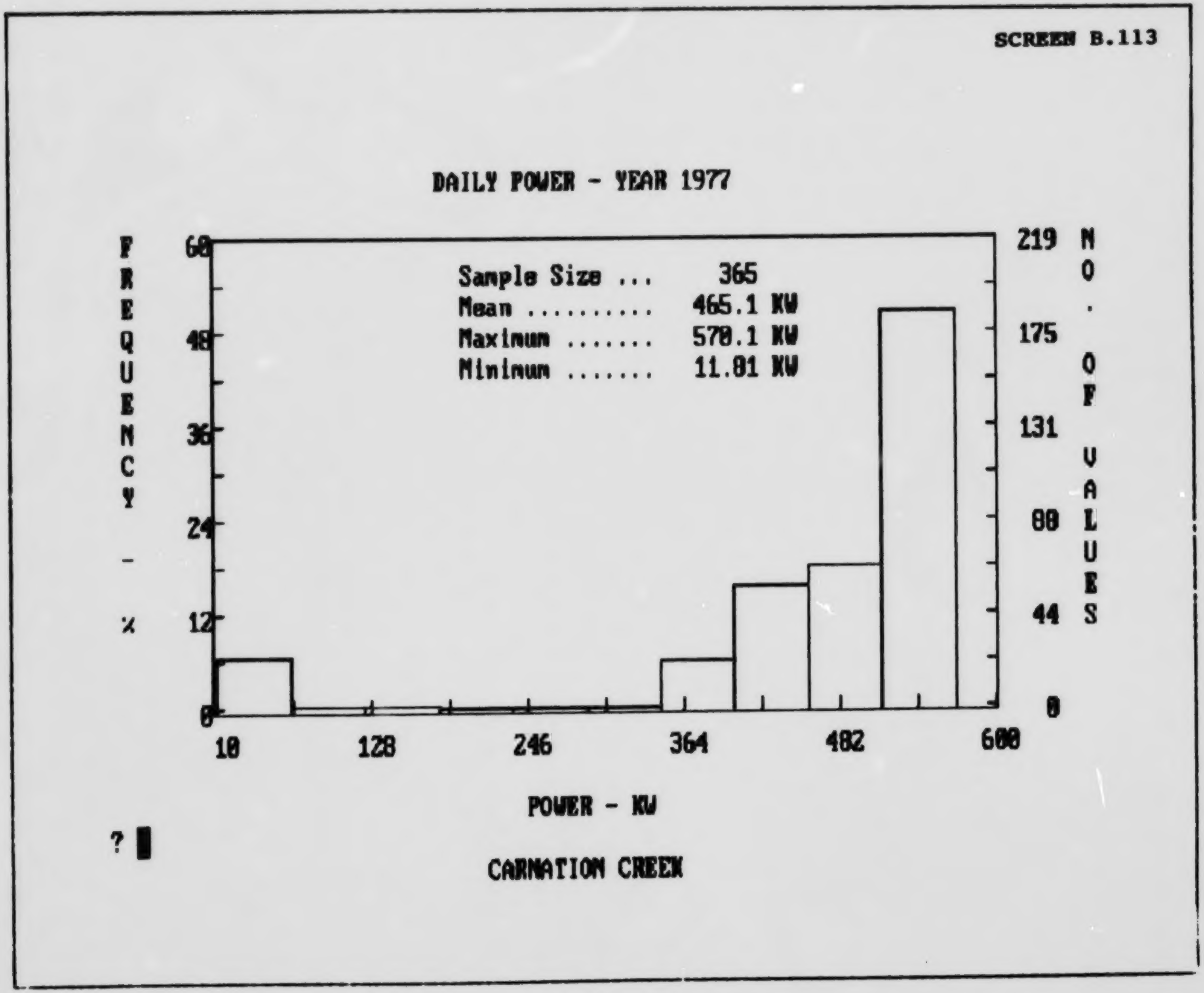


```
                                                                    SCREEN B.111



DAILY POWER - YEAR 1977
CARNATION CREEK

     INTERVAL          PLOT   PLOT       PERCENTAGE       PROBABILITY  NO. OF
    FROM      TO       POSN. POSN/AV     FREQ.   CUM.       DENSITY    VALUES
    -----------        -------------     ------------     -----------  ------
    11.8      67.6      39.7    0.085     6.85     6.85    0.0012267       25
    67.6     123.5      95.6    0.205     0.55     7.40    0.0000981        2
   123.5     179.3     151.4    0.326     0.55     7.95    0.0000981        2
   179.3     235.1     207.2    0.446     0.27     8.22    0.0000491        1
   235.1     291.0     263.1    0.566     0.27     8.49    0.0000491        1
   291.0     346.8     318.9    0.686     0.27     8.77    0.0000491        1
   346.8     402.6     374.7    0.806     6.30    15.07    0.0011286       23
   402.6     458.5     430.6    0.926    15.62    30.68    0.0027970       57
   458.5     514.3     486.4    1.046    18.36    49.04    0.0032877       67
   514.3     570.1     542.2    1.166    50.96   100.00    0.0091269      186
*******************************************************************************
  MAX =  570.1     MIN = 11.806    MEAN =465.08      STD. DEV. = 140.14
*******************************************************************************

Would you like TABLE again ? (Y/N) :?
```



```
                                                            SCREEN B.112


   FOR X-AXIS : POWER - KW
   ==========   ----------
                ACTUAL MIN =  11.8           ACTUAL MAX =   570.1

   FOR Y-AXIS : FREQUENCY - %
   ==========   -------------
                ACTUAL MIN =  0.3           ACTUAL MAX =   51.0


   SCALES ON GRAPHICS : ( MAX - MIN MUST BE EVENLY DIVISIBLE BY 1 )
   ==================
   FOR POWER - KW ON X-AXIS :              MIN = ? 0
                                          MAX = ? 600

   FOR FREQUENCY ON Y-AXIS :              MIN = ? 0
                                          MAX = ? 60
```

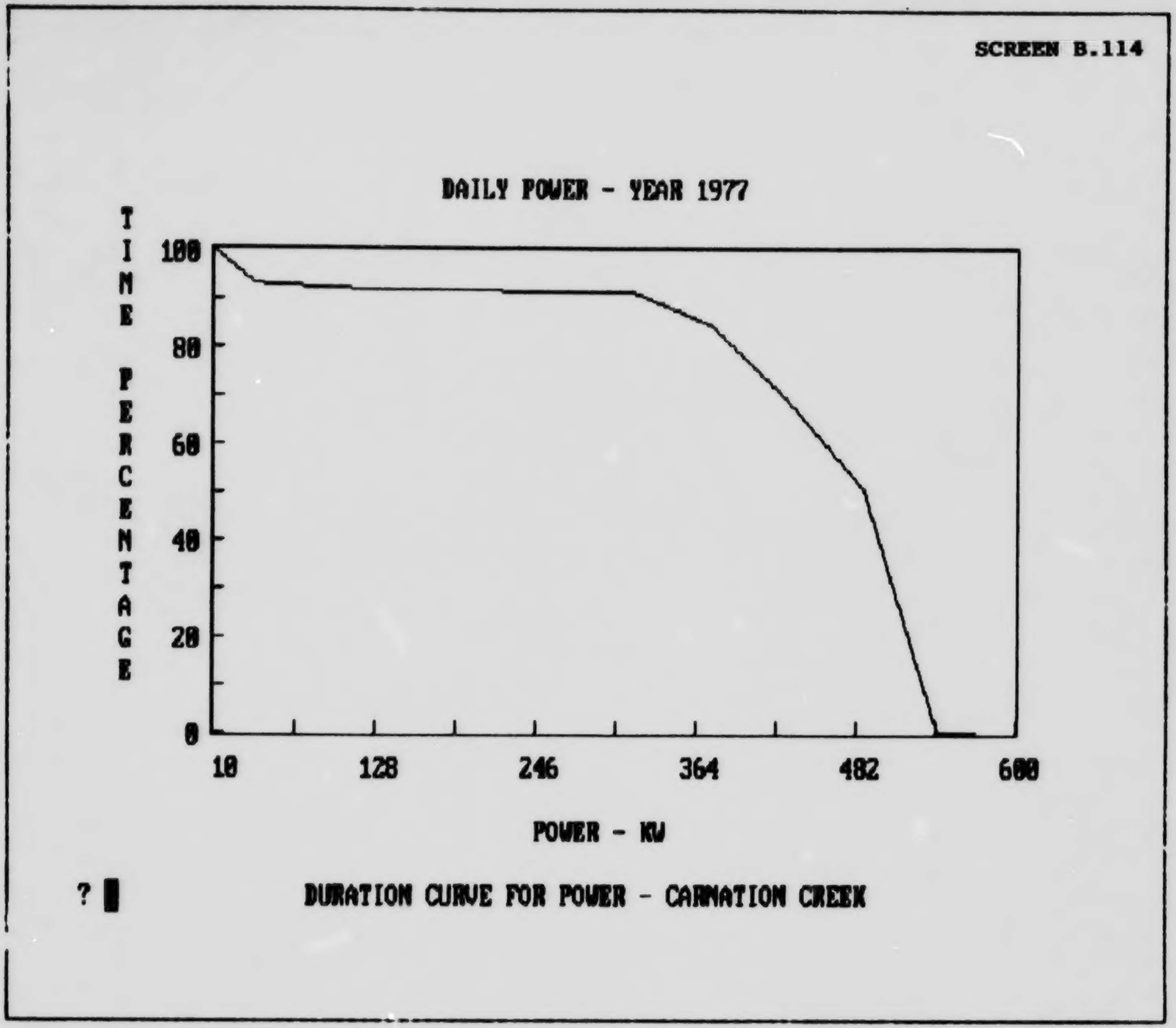
SCREEN B.113



DAILY POWER - YEAR 1977

```
Sample Size ...     365
Mean ..........   465.1 KW
Maximum .......   570.1 KW
Minimum .......   11.01 KW
```

FREQUENCY - %
60
48
36
24
12
0
NO. OF VALUES
219
175
131
88
44
0
10
128
246
364
482
600
POWER - KW
? ▮
CARNATION CREEK



SCREEN B.114

DAILY POWER - YEAR 1977

TIME PERCENTAGE
100
80
60
40
20
0
10
128
246
364
482
600
POWER - KW

? ▌

DURATION CURVE FOR POWER - CARNATION CREEK

INTEGRATED METHOD FOR POWER ANALYSIS (IMP)

SECTION III - THEORY AND MODELING PROCEDURES

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1. INTRODUCTION

IMP provides a method for evaluating small-scale hydroelectric power sites in British Columbia. The package contains numerous utility routines which organize and display data using methods which should be obvious to anyone familiar with this type of computer work. However, there are four major programs in the package which are based on theoretical considerations that require more explanation.

The following four programs are discussed in detail in this Section:

1. The Atmospheric Model developed by Danard for the B. C. Ministry of the Environment, which was used by him to generate average annual precipitation and 24-hour one-in-ten year maximum rainfall on a closely spaced grid which spans most of the Province. These grid data were stored as part of the **IMP** package, and a computer program to retrieve them is provided.

2. The Flood Frequency methodology, based on the mathematical method of derived probability distribution functions. Several clients have contributed to the development of this program.

3. The Watershed Model, which performs a daily snow accumulation and melt accounting based on the area-elevation curve for the watershed, and which allocates runoff to different components of the hydrograph. This program was rewritten in BASIC based on the FORTRAN code of the UBC Watershed Model.

4. The Power Study Methodology, which incorporates a linear programming procedure to maximize energy production within constraints on the reservoir, penstock and powerhouse capabilities. The first version of this program was developed for B. C. Hydro.

Much of this Section was developed by editing existing material which describes each of the above models. The editing consisted of modifying the descriptions to conform with the implementations in **IMP** and adding clarifying comments where appropriate.

2. THE ATMOSPHERIC MODEL

IMP contains a data base of average annual precipitation and 24-hour maximum, one-in-ten year rainfall on a ten minute latitude -longitude grid.

The grid point precipitation data base was prepared by M. B. Danard, a meteorological consultant to the B.C. Ministry of

Environment, over a period of several years. The modeling procedure which he used is described in his reports, from which Section 2.1 and 2.2 are quoted with minor editing. The 24-hour maximum rainfall grid is not essential to **IMP** but the data base and the discussion below in Section 2.2 are included because they might assist users in understanding the climate and hydrology of B.C.

2.1 Method of Analysis - Average Annual Precipitation

The vertical flux of water due to orography is given by

$$P_m = (\rho q+W) \quad (u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y}) \tag{2.1}$$

where is the air density, q the specific humidity, W the mass of condensed water per unit volume (taken as 1 gm m^{-3}), u and v are the x and y velocity components, and h/ x and h/ y are the components of the terrain slopes. All meteorological variables in Equation 2.1 are 850 mb values.

For the coastal area (west of the Coast Mountains), we include the vertical moisture flux due to frictional convergence

$$P_f = (\rho q + W) w_f \tag{2.2}$$

where w_f is the frictionally induced vertical velocity at 850 mb. Details of the computation of w_f are given in Report No. 17., Danard (1975).

Falling precipitation is assumed to be blown downwind by the 850 mb wind a distance

$$D = \frac{Vd}{w} \tag{2.3}$$

where V is the 850 mb wind speed, d = 1.7 km is the distance a snowflake is assumed to fall before melting, and w = 75 cm/s is the assumed fall velocity of a snowflake.

Danard divided the Province into four regions:

1. Coastal - west of the Coast Mountains and south of the Alaskan Panhandle.

2. Southern interior - east of the Coast Mountains and south of 51° 05'N.

3. Northern interior - between the Coast and Rocky Mountains and north of 51° 05'N.

4. Northeastern - east of the Rocky Mountains.

The areas over which terrain slopes are averaged are 1° 20' lat. by 2° 00' long. for region 1 and 1° 40' lat. by 2° 40' long. for regions 2 - 4. Observed mean (1941-70) precipitation amounts P (Atmospheric Environment Service) are fitted to the following equations, allowance being made in each instance for downwind displacement of falling precipitation.

Region 1: $$P = a(P_m + P_f) + b \qquad (2.4)$$

Regions 2,3,4: $$P = a\,P_m + b \qquad (2.5)$$

Meteorological data used are given in Table 3.1.

Table 3.1 850 mb DATA

REGION	WIND SPEED	DIRECTION	DEWPOINT
1	14m/s	200°	5°C
2	16	251°	0
3	3.2	241°	-1.5 *
4	4.7	001°	4

* Prince George

Except for region 3 (the one with the greatest area) the values in Table 3.1 are assumed constant over the regions. In region 3, the specific humidity is allowed to vary linearly with latitude (corresponding to the mean dewpoint gradient given in Titus (1967). The physical interpretation of the constant "b" in Equation 2.5 is the precipitation over flat terrain. This, too, is permitted to decrease with latitude in region 3 only. The differences between actual precipitation amounts and those predicted by Equation 2.5 were fitted to a linear function of latitude. Results of fitting Equations 2.4 and 2.5 are shown in Table 3.2.

Table 3.2 REGRESSION COEFFICIENTS FOR EQUATIONS 2.4 AND 2.5
Standard Errors (S) and Coefficients of Variation (C)
for P, P_m and S in Inches/Year

REGION	SAMPLE SIZE	a	b	S	C
1	195	0.041	51.0	23.4	0.34
2	95	0.025	19.0	6.5	0.30
3	42	0.11	variable	8.9	0.38
4	8	0.0017	16.9	1.0	0.06

Let $_n$ be the residual, actual precipitation minus that predicted by the regression Equations 2.4 or 2.5 for the n^{th} station (See Figure 3.1).

Compute the weights

$$W_{mn} = (1 - r_m^2) \;/\; \sum_m (1 - r_m^2) \qquad (2.6)$$

where m = 1,2,3,4 denotes the four grid points surrounding the station. The distances r_1, r_2, etc. are expressed as fractions of the grid distance. If the station lies exactly on a grid point, W = 1 for that grid point. W decreases with increasing distance between the station and a grid point. For $r_m = 1$, $W_{mn} = 0$. Note that $_m W_{mn} = 1$. For each of the four surrounding grid points which have W_{mn} 0, compute the weighted residual

$$E_{mn} = \varepsilon_n W_{mn} \;;\; m = 1,2,3,4 \qquad (2.7)$$

A given station may affect as many as four grid points (i.e., up to four grid points may lie within one grid distance of the station and have W_{mn} 0).

Repeat the above procedure for all stations. Next adjust all grid points for which E_{mn} has been calculated (i.e., those grid points which have at least one station within a radius of one grid distance). If P is the unadjusted grid point precipitation (i.e., predicted by the regression Eq 2.4 or 2.5), compute the adjusted precipitation P_a in the following manner:

$$P_a = P + \Sigma\, E_{mn} / \,\Sigma\, W_{mn} \qquad (2.8)$$

In Equation 2.8, the summation extends over all stations affecting the grid point. These stations must lie in the four grid squares surrounding the grid point. In each term of the summation m takes on one value only.

This technique ensures that where data exist, values interpolated at the stations from grid point values will agree with the station values. Finally, the grid point precipitation amounts are lightly smoothed. The standard errors and coefficients of variation (standard error divided by the mean precipitation) refer to grid points where data are not available. In regions where data are present, errors will be zero or nearly so, (see footnote, p. III-8).

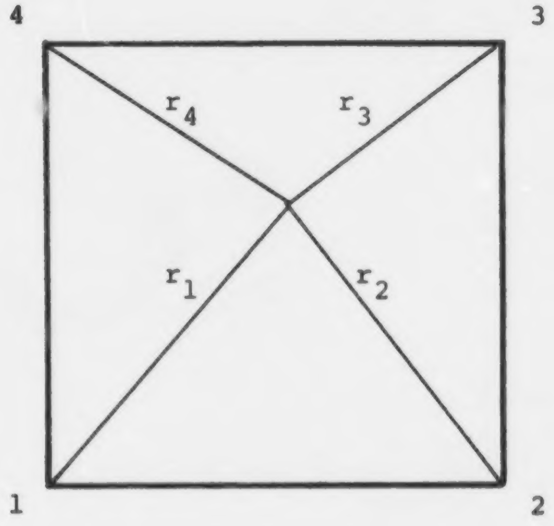


Figure 3.1 SCHEMATIC DIAGRAM FOR GRID POINTS

(showing location of station at 0 in relation to the four surrounding grid points 1, 2, 3 and 4.

2.2 Method of Analysis - Heavy Precipitation

There are two radiosonde stations in northern interior B.C., Prince George and Fort Nelson. Mean 850 mb conditions were determined during heavy precipitation days ($>$ 0.5 inches at Prince George and 0.4 inches at Fort Nelson in 1975 and 1976). Results are shown in Table 3.3. There is a significant difference between the two stations. Prince George's west-southwest wind direction is similar to that found for the southern interior and southwestern coastal B.C. On the other hand, Fort Nelson has a north wind. Meteorologically speaking, northeastern B.C. is similar to Alberta which occasionally has heavy large-scale summer rainstorms (Hage 1961). A north wind at Fort Nelson is consistent with a low pressure area to the east. Of Fort Nelson's heavy precipitation days, 89% occur in June, July and August. In contrast, only 29% of Prince George's greatest precipitation days occur in these three months. Therefore it was decided to treat the northern interior as two regions: (1) the area between the Coast and Rocky Mountains, and (2) the region east of the Rockies (the northeastern part of the province).

Table 3.3 WIND AND DEWPOINT DURING HEAVY PRECIPITATION

LOCATION	DIRECTION	SPEED	DEW-POINT
Prince George	241°	3.2 m/s	-1.5°C
Fort Nelson	001°	4.7 m/s	4.0°

24-hour rainfall amounts for various return periods, calculated by the Atmospheric Environment Service, are shown in Table 3.4. These were computed from climate day amounts (8 a.m. to 8 a.m.) and then multiplied by 1.13 to apply to any 24 consecutive hours. Note the high values at Fort Nelson and Fort St. John.

For the area between the Coast and Rocky Mountains (i.e., excluding Fort Nelson and Fort St. John), the following equation was fitted to the 24-hour rainfall amounts for various return periods (r):

$$r = a + b\ P_m \qquad (2.9)$$

Table 3.4 24-HOUR RAINFALL AMOUNTS

STATION	LATITUDE	LONGITUDE	RETURN PERIOD (YRS)				
			2	5	10 (Inches)	25	50
Atlin	59°34'N	133°42'W	0.76	1.11	1.32	1.60	1.81
Barkerville	53°04'	121°31'	1.22	1.62	1.88	2.21	2.45
Blue River	52°09'	119°17'	1.34	1.64	1.84	2.09	2.27
Dease Lake	58°25'	130°00'	0.88	1.32	1.60	1.97	2.24
Fort Nelson	58°50'	122°35'	1.30	1.94	2.45	3.03	3.46
Fort St. John	56°14'	120°44'	1.39	2.54	3.20	3.65	4.09
Golden	51°18'	116°58'	1.21	1.76	2.11	2.57	2.90
Prince George	53°53'	122°40'	1.14	1.50	1.74	2.03	2.26
Smithers	54°44'	127°06'	1.13	1.56	1.87	2.23	2.52
Williams Lake	52°11'	122°04'	0.88	1.31	1.59	1.94	2.20

P_m was calculated using Prince George's mean 859 mb conditions given in Table 3.3 and allowing q in Equation 2.1 to decrease linearly with latitude (corresponding to the mean dewpoint gradient given in Titus, 1967). Allowance was made for downwind displacement of falling precipitation. Regression coefficients are given in Table 3.5. The coefficient "a" in Equation 2.9 represents the rainfall amount over flat terrain ($P_m = 0$) and this too should decrease with latitude. However, the regression analysis gives a constant "a" which generally results in r being too low in the south and too high in the north. Therefore, the differences between the actual rainfall amounts and those predicted by Equation 2.9 were fitted to a linear function of latitude. The correlation coefficients and standard errors using this modified procedure are shown in Table 3.5.

For the northeastern part of the province, we have only two stations, Fort Nelson and Fort St. John. Thus the following procedure is employed. First P_m is computed from the 850 mb values for Fort Nelson given in Table 3.3 allowing as before for downwind displacement of falling precipitation. The values of b were assumed to be the same as those given in Table 3.5 for the

Table 3.5 COEFFICIENTS OF REGRESSION, CORRELATION AND STANDARD ERROR

Regression coefficients of Equation 2.9, and multiple correlation coefficients c and standard errors s between actual return period rains in the region between the Coast and Rocky Mountains and those predicted by Equation 2.9 using values of "a" decreasing linearly with latitude (see text). For a, s, r and P_m in inches/24-hours.

Return Period (Years)	a	b	c	s
2	0.98	1.15	0.81	0.13
5	1.38	1.25	0.85	0.12
10	1.64	1.29	0.81	0.15
25	1.97	1.40	0.76	0.19
50	2.22	1.42	0.70	0.24

area to the west of the Rockies. The coefficient "a" was again assumed to be a linear function of latitude and was determined by the values of ($r - b P_m$) at Fort Nelson and Fort St. John. This guarantees that Equation 2.9 will fit the values at the two stations exactly.

Along the summit of the Rockies, we have two estimates, one from the interior region and one from the northeastern. The larger of the two values was taken as correct.

For each grid point (every 10' long. and lat.) the 24-hour rainfall amount was calculated as described above. To make sure the final array agrees with the station values (Table 3.4), the four grid points surrounding an observation were adjusted by amounts equal to the disparity between the actual value at the station and the value interpolated there from the grid point values.*

---

*Note: This procedure used by Danard adjusted the grid point values surrounding the stations. However the remaining points in the grid have not been adjusted and therefore still contain any errors which are inherent in the modelling procedure (See also 6.1 in this Section and Table 2.1 of Section II).

Intuitively one would expect the 24-hour rainfall for various return periods to be positively correlated with mean annual precipitation or rainfall. Such relationships would be useful since annual values are available for many more stations that are 24-hour values. Accordingly, the following regression equations were determined:

$$\begin{gathered} r_n = a + b\,P \\ \text{or} \\ r_n = a + b\,R \end{gathered} \tag{2.10}$$

where r_n is the 24-hour rainfall for an n-year return period, P is the mean annual precipitation and R is the mean annual rainfall. Results for most of the Province are shown in Table 3.6. The values apply to any 24 consecutive hours (the climate day or 8 a.m. to 8 a.m. values are multiplied by 1.13 to allow for this). The correlations are highest in areas 1 and 2 and least in region 3. In region 3 heavy rainfall frequently occurs in local thunderstorms rather than in large-scale weather systems. This probably contributes to a lower correlation there than elsewhere. Also, area 3 is much larger than areas 1 or 2.

It is important to point out here that the method used by Danard to construct the 10-minute latitude-longitude grid results in precipitation values at the grid points which are not necessarily (in fact, probably will not be) the precipitation values at ground elevation, but rather at some unknown elevation related to the elevation of the nearest AES station. The user is therefore cautioned to exercise care in applying grid values. For more detail, see the discussion in Section IV. Furthermore, there are some locations, particularly in the northwestern corner of the Province, where no grid data are available.

Table 3.6 COEFFICIENTS OF REGRESSION, CORRELATION AND STANDARD ERROR, AREAS 1, 2 AND 3

Regression coefficients of Equation 2.10, and standard error and correlation coefficient between predicted and actual 24-hour rainfall, for r_n, and R in inches. Area (1) is southwestern coastal B.C. (west of the Coast Mountains and south of 51° N); area (2) is southern interior B.C. (east of the Coast Mountains to the Alberta border and south of 51° N); area (3) is northern interior B.C. (east of the Coast Mountains to the Alberta border and north of 50° 40'N).

Area	No. of Stations	Return Period (yrs)	Predictor	Regress.	Coeffs.	Standard Error	Corr. Coeff.
1	46	2	P	.46	.037	.28	.98
2	11	2	P	.54	.022	.08	.93
			R	.51	.033	.10	.91
3	14	2	P	.65	.022	.32	.68
			R	.59	.038	.25	.82
		5	P	1.12	.023	.56	.48
			R	1.04	.042	.51	.61
		10	P	1.45	.023	.71	.41
				1.31	.045	.65	.55
		25	P	1.75	.026	.86	.38
			R	1.58	.052	.79	.53
		50	P	2.02	.027	.97	.36
			R	1.81	.056	.90	.51

3. THE FLOOD FREQUENCY MODEL

For every stream or river for which hydrometric data are available, there are many for which no data are available. The need to provide a rational approach to design of bridges, culverts and small dams on ungauged watersheds has led to innumerable empirical methods and rules-of-thumb. In many cases, these approaches are adequate for average conditions in the region for which they were developed, but application to extreme events or to new regions is either impossible or dubious. The flood frequency method for ungauged watersheds presented in this report has more general application. Both large and small watersheds can be modelled, as well as diverse climatological and geographic regions and the watershed modeling parameters which must be estimated are physically meaningful.

3.1 Use of Climatological Data to Define Probability

The fundamental input to a watershed is the liquid water deposited as rain or snow. The climatological data which is involved in runoff includes direct measurements of the quantities of these liquid water sources, their availability in time, and in the case of snow, those parameters which contribute to melting. In this section, climatological data are discussed considering only those aspects which influence the analysis of direct runoff - the principal component of a flood hydrograph.

3.2 Definition of Rainfall Events

One of the major purposes of this work is to provide convenient methods for estimating the probability of runoff events. These estimates are developed by mathematical transformations on the probability of certain rainfall (and snowmelt) properties. An important step in the analysis is, therefore, to determine the probability behaviour of the rainfall -- before this can be done it is necessary to define what is meant by a rainfall event.

Rainfall does not take place continuously but consists of a sequence of discrete periods of rainfall, of varying average intensity, followed by periods without precipitation. Occasionally the rainfall stops only briefly, to begin again later. For some purposes it might be reasonable to ignore the brief rain-free interlude and to consider the event as a single longer duration rainfall with average intensity reduced by the brief period without rain. The duration of the rain-free period and the anticipated runoff behaviour of the watershed are important considerations in making this judgment. If the watershed is large it might be expected that a short, temporary reduction in rainfall could not show up in a measured hydrograph. Furthermore, if the rain results from a synoptic disturbance, covering a large region, the temporary interruption might properly be ignored on the physical grounds that the synoptic disturbance is the event of interest, not the minor variation in its detection as measured by the raingauge.

The frequency response of the watershed also enters into the definition of an event. This aspect can be investigated by examining the Fourier cosine transform of the autocorrelation function of rainfall. Such a transformation yields the "power" spectrum $\Phi_p(w)$ of the rainfall data and provides a display of the frequency characteristics of rainfall. The calculation is accomplished by:

$$\Phi_p(w) = \frac{1}{2\Pi} \sum_{\tau = \phi}^{\tau = \tau_{max}} \phi(\tau) e^{-jw\tau} \Delta\tau \tag{3.1}$$

in which the frequencies, w, are related to the "period" of events by:

$$w = \frac{2\Pi}{T} \tag{3.2}$$

This same type of calculation can be made on the continuous, long term hydrograph of direct runoff to produce the frequency spectrum of the transient portion of runoff Φ_R. Figure 3.1 illustrates typical rainfall and runoff spectra in which the higher frequencies in the rainfall time series do not appear in the runoff. The natural hydraulic damping processes of the watershed and stream have acted to filter out the short duration rainfall fluctuations. This comparison will also suggest that a cut-off frequency for the rainfall analysis can be at w_c. Frequencies higher than this would have little effect on the runoff record and could be "smudged" into lower frequencies. The corresponding cutoff period T_c can be calculated from Equation 3.2 and the maximum sample interval to define such frequencies is $t_*/3.2$ as given by Harley (1977), in which t_* is the time of concentration. Considering the watershed's effects on rainfall, it would be adequate to recognize rainfall intensity variations which take place over periods of time greater than $t_*/3.2$.

Often there are no streamflow records available and the cutoff frequency for the watershed cannot be estimated directly, as outlined above. In this case, the time of concentration of the stream and catchment combination, calculated as explained below, provide the basis for selecting an appropriate event time scale. The definition of a rainfall event should consider the natural damping effect of the watershed, and the rainfall data should not be smudged by averaging events which take place within $t_*/3.2$ of

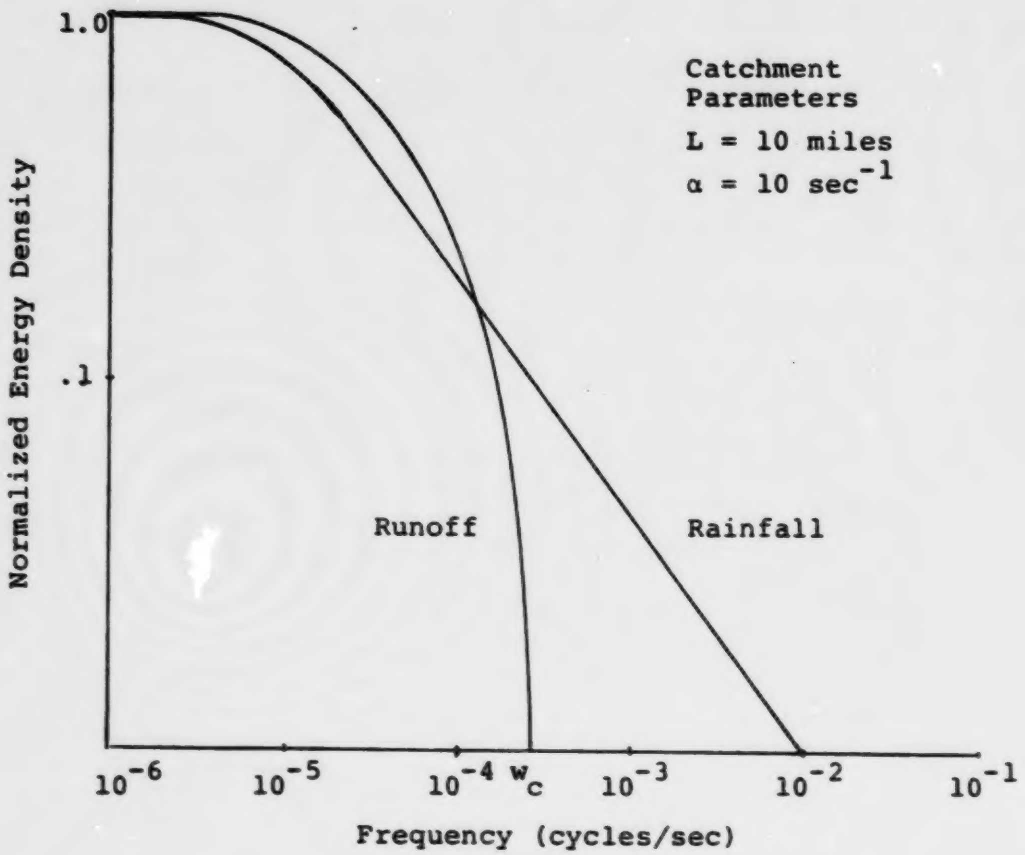


Figure 3.2 **RAINFALL AND RUNOFF SPECTRA**

each other. In practice this means that, for example, if the time required for a hydrograph to reach peak discharge is more than 3.2 hours then hourly rainfall data provides sufficiently fine resolution for estimating peak flows. Daily averaged rainfall data could be used for watersheds that require 3.2 days or more to reach peak flow. For **IMP**, the flood frequency analysis was based on statistics of hourly rainfall and an empirical relationship with the average annual precipitation values provided by the grid values of the Atmospheric Model described in the previous Section.

3.3 Probability Density Function

The rainfall data series can be grouped into a series of individual independent events, each with its own duration, average intensity, depth (volume) and each separated from the previous event by an interval longer than one hour. These characteristics of the individual, independent events may then be subjected to frequency analysis to determine their probability distribution. Figures 3.3 and 3.4 present some examples of distributions which were calculated from actual data. These results are typical of what has been found from analyzing rainfall data of many other climatological stations (Flatt and Howard, 1978).

The duration of rainfall events has a probability density function which is approximately exponentially distributed as illustrated in Figure 3.3 The equation for this distribution is

$$f_{tre}(t_o) = \lambda e^{-\lambda t_o} \tag{3.3}$$

The first and second moments (mean and standard deviation) of this distribution is $1/\lambda$ and it can, therefore, be estimated from the mean storm duration. Alternatively some fitting procedure could be used to estimate λ by minimizing deviations from the actual histograms. In practice λ is estimated by the reciprocal of the average rainfall event duration.

The main advantage of Equation 3.3 is its simplicity; this feature is also its main disadvantage because a good fit to both average and more extreme events may not be possible with such a single parameter distribution.

Rainfall event intensity (averaged over each event) and the inter-event time can also be represented statistically by

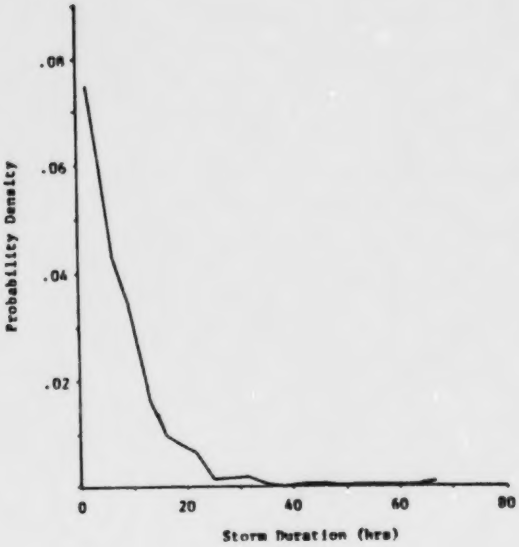


Figure 3.3 PROBABILITY DENSITY FUNCTION, STORM DURATION

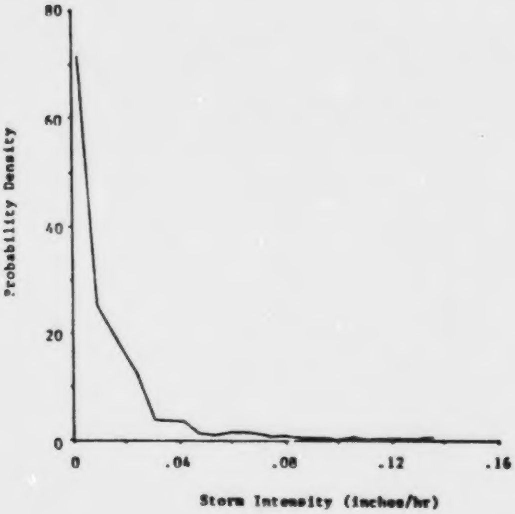


Figure 3.4 PROBABILITY DENSITY FUNCTION, STORM INTENSITY

exponential probability density functions. Thus, for intensity, i,

$$f_i(i_o) = \beta e^{-\beta i_o} \tag{3.4}$$

in which β is again both the first and the second moments and is adequately represented by the reciprocal of the mean value.

In practice the data are recorded at discrete intervals and the continuous exponential distribution shown above may provide inappropriate results for values near zero. This can be avoided by taking care to use a minimum lower limit equal to the sample interval and to normalize all distributions to account for this procedure. For example, the sample interval for rainfall duration is often one hour and this is, therefore, the shortest duration which could be recorded for a rainfall event. The distribution for rainfall duration should, therefore, be normalized bv dividing it by the factor N, given by,

$$N = \int_{t=o}^{t=1} \lambda e^{-\lambda t}\,dt \tag{3.5}$$

The probability of rainfall event durations between 1 and 2 hours is then given by,

$$\text{Prob}\,\{1 \leq t_{re} \leq 2\} = \frac{1}{N} \int_{t=1}^{t=2} \lambda e^{-\lambda t}\,dt \tag{3.6}$$

and the probability of all durations is,

$$\frac{1}{N} \int_{t=1}^{t=\infty} \lambda e^{-t}\,dt = 1 \tag{3.7}$$

Similar normalizations should be applied to the other continuous distributions when they are estimated from discrete data.

3.4 Probability and Return Period

The probability density functions of rainfall can be used to calculate the probability of certain event characteristics. For example, the probability of a rainfall duration exceeding, say, t_n hours is,

$$\text{Prob}\,\{t_n < t_{re} < \infty\} = \frac{1}{N} \int_{t=t_n}^{t=\infty} \lambda e^{-\lambda t}\,dt \tag{3.8}$$

which upon integration reduces to:

$$\text{Prob}\ \{t_n < t_{re} < \infty\} = \frac{e^{-\lambda t_n}}{N} \tag{3.9}$$

Thus, when a rainfall event occurs, the probability that the duration will exceed t_n hours is Equation 3.5. The number of independent events which, on the average, would have to occur before one had a duration of t_n hours or greater is the reciprocal of this probability or, $Ne^{\lambda t_n}$. If there is an average of Θ events each year then the return period is the number of events necessary divided by the number of events each year, i.e., $\frac{Ne^{\lambda t_n}}{\Theta}$.

This defines the return period T_e,

$$T_e(t_n) = \frac{Ne^{\lambda t_n}}{\theta} \tag{3.10}$$

or, more generally, the return period of an event j, is

$$Te(j) = \frac{1}{\theta\ \text{Prob}\ (j)} \tag{3.11}$$

In many cases it is useful to be able to estimate the return period of a combination of events after the probabilities of these have been defined by some other analysis. For example, flood frequency curves developed from measured streamflow may include spring floods caused primarily by snowmelt with those caused by rainfall later in the year. It is often realistic to assume that these are independent and in such a case it is easy to disaggregate the flood frequency curve into two components by investigating snowmelt and rainfall separately.

Suppose the return period of a snowmelt or rainfall flood peak of magnitude Q_p is T_s and T_r respectively. The probabilities of these floods occuring during any one year are the reciprocals of T_s and T_r. Thus, the probability of no flood exceeding Q_p in a given year is:

$$\text{Prob}\ \{Q < Q_p\} = (1 - {}^{1}/T_r)\ (1 - {}^{1}/T_s) \tag{3.12}$$

The probability of a flood greater or equal to Q_p is then:

$$\text{Prob}\ \{Q \geq Q_p\} = 1 - (1 - {}^1/T_r)\ (1 - {}^1/T_s) \tag{3.13}$$

and the return period for a Q_p flood is the reciprocal:

$$T_e\ (Q_p) = \frac{1}{1 - (1 - {}^1/T_r)\ (1 - {}^1/T_s)} \tag{3.14}$$

which reduces to:

$$T_e\ (Q_p) = \frac{T_r\ T_s}{T_r + T_s - 1} \tag{3.15}$$

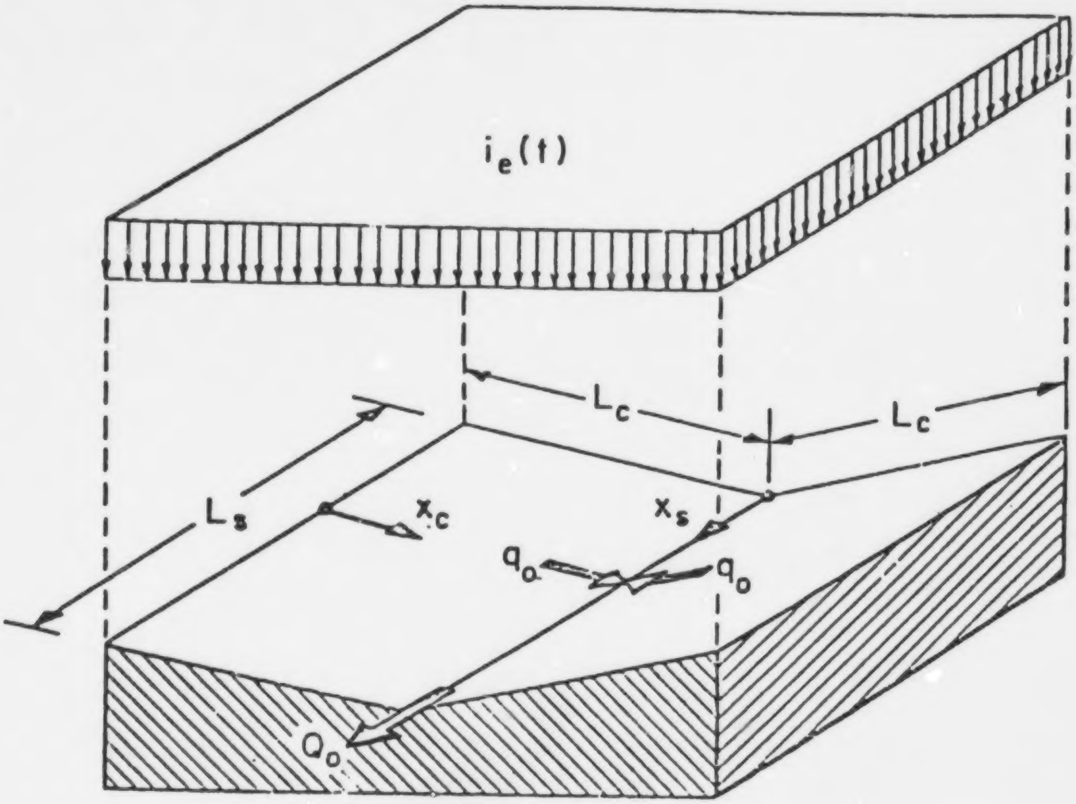
3.5 The Flood Frequency Watershed Model

The watershed can be thought of as consisting of a **catchment area** which routes water to a **stream channel**. Obviously, each of these components of the watershed includes many details and some of these may be very important to the analysis. However, if we restrict our interests to rare flood events, these details can be lumped into a manageable number of coefficients which are surrogate representations of the real watershed. For the present, we will deal with the watershed concept illustrated in Figure 3.5. The watershed is assumed to consist of two equally sloping planes leading down to a central stream channel of uniform width and slope throughout its length.

This watershed performs an hydraulic transformation on the liquid water input to it. If groundwater flows, evapotranspiration, and other factors are unimportant, as would be the case during a flood, these transformations are represented algebraically through solutions to the equations of motion. Solving these equations, using a kinematic wave model gives the time of concentration of the catchment, t_c, and the stream channel, t_s, by:

$$t_c = 0.914 \left[\frac{n_c\ A_r}{\sqrt{S}_c\ L_s\ \bar{i}_e}\right]^{1/2} \tag{3.16}$$

$$t_s = 0.130 \left[\frac{P_s\ n_s^2}{S_s\ A_r\ \bar{i}_e}\right]^{1/3} \tag{3.17}$$


$i_e(t)$
L_c
L_c
L_s
x_c
x_s
q_o
q_o
Q_o

PHYSICAL CHARACTERISTICS

Catchment	Stream
Slope, s_c	Slope, s_s
Area, A_c	Length, L_s
Hydraulic Roughness, n_c	Hydraulic Roughness, n_s
Length, L_c	Wetted Perimeter, P_s

Figure 3.5 WATERSHED CONCEPT

where the constants in Equations 3.16 and 3.17 (English unit) are:

L_s = length of stream (miles)
A_r = area of catchment contributing to runoff (sq. mi.)
P_s = wetted perimeter of stream at location of interest (feet)
s_c = slope of the catchment (overland flow path)
s_s = slope of the stream
n_c = Manning's n for the catchment (typically 0.3)
n_s = Manning's n for the stream
i_e = storm averaged rate of rainfall excess (in/hr)

The total time of concentration of the catchment and stream, t_*, is given by:

$$t_* = t_c + t_s \tag{3.18}$$

Equation 3.18 can be rewritten using 3.16 and 3.17 to give:

$$t_* = a\bar{i}_e^{-1/2} + b\bar{i}_e^{-1/3} \tag{3.19}$$

The parameters a and b, therefore, represent the time of concentration of the catchment and stream for an average intensity of one. Figure 3.6 shows the variation of the total time of concentration in hours for a small catchment. If actual hydrographs and corresponding rainfall or snowmelt are available, a and b can be estimated from actual data by calibration.

For the watershed model, if the rainfall duration at the "steady" rate i_e exceeds the time of concentration t_*, "steady" flow will be reached on the watershed. Since the flow is "steady", the rate of outflow is directly proportional to the rate of input of liquid water. Thus, the peak discharge, Q_p, is given by:

$$Q_p = 645\ KA_r\bar{i}_e\ , \quad t_{re} > t_*(\bar{i}_e) \tag{3.20}$$

in which the constant, 645, supplies the appropriate conversion of units with i_e in inches/hour, A_r in sq. miles, Q_p in cfs, and K is a factor which prorates point rainfall to the entire watershed.

3.6 Flood Probability

The "steady" flow formula, Equation 3.20 is applicable to the joint occurrence of an intensity, i_e, and an associated rainfall

PEARSON CREEK

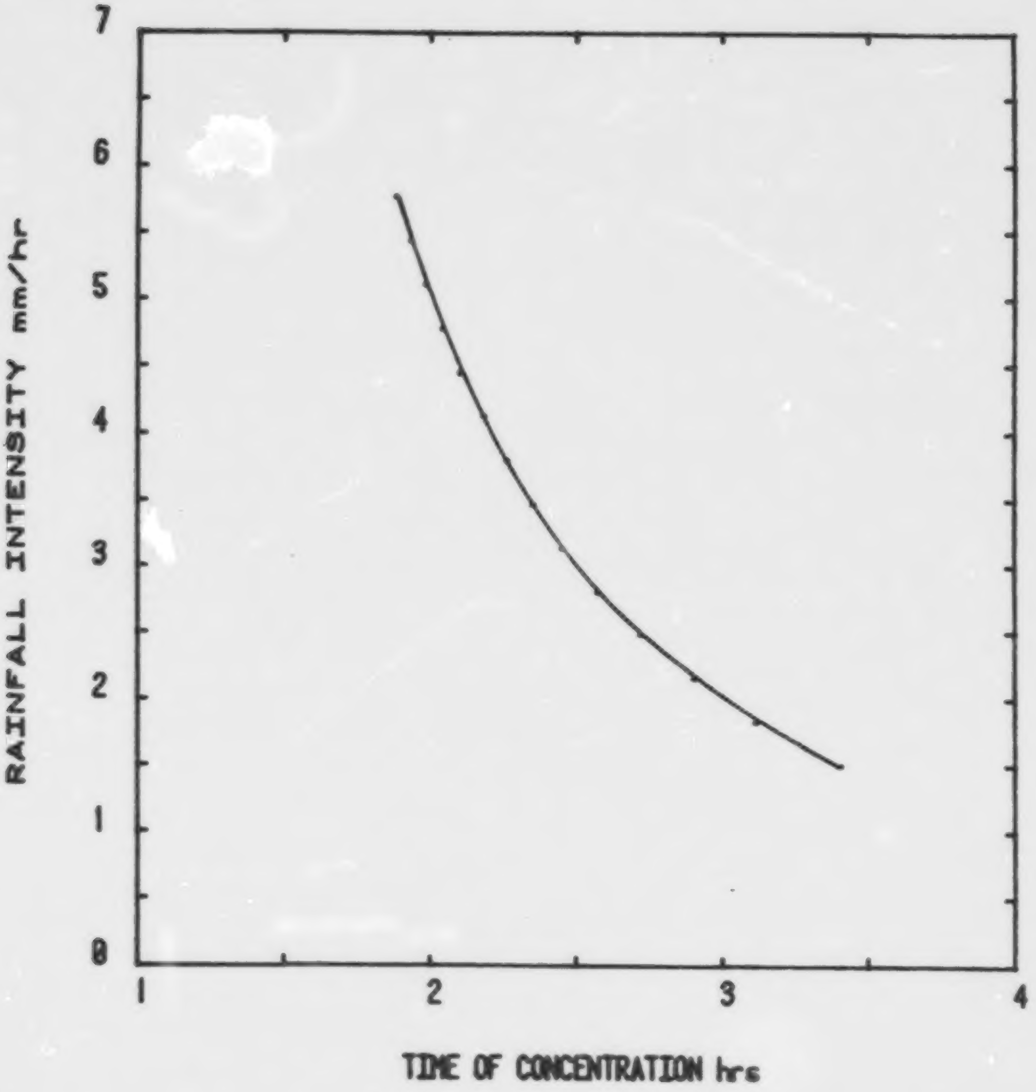


Figure 3.6 EFFECT OF RAINFALL INTENSITY ON TIME OF CONCENTRATION

duration which exceeds the value of a function of i_e. The probability of Q_p is not related only to the probability of i_e but to this **joint** occurrence.

The estimation of the return period of Q_p requires evaluation of the joint probability density function describing the occurrence of t_{re} and i_e.

$$\text{Prob}\ |Q \geq Q_p| = \text{Prob}\ \left\{ \bar{i}_e \geq \frac{Q_p}{645KA_r}\ \middle|\ t_{re} \geq t_*\ (\bar{i}_e) \right\} \qquad (3.21)$$

$$\text{Prob}\ |Q \geq Q_p| = \int_{\bar{i}_e = \frac{Q_p}{645KA_r}}^{\bar{i}_e = \infty} \int_{t_{re} = t_*}^{t_{re} = \infty} f_{\bar{i}_e, t_{re}}(i_o, t_o)\ dt_{re}\ d\bar{i}_e \qquad (3.22)$$

in which $f_{\bar{i}_e,\, t_{re}}(i_o, t_o)$ is the desired joint probability function for determining flood probability. Since i_e and t_{re} are independent this function is simply the product of the two marginal distributions.

3.7 Evaluation of Flood Probability

The basic method used is to integrate the joint probability distribution for rainfall intensity and duration over limits which are determined by the watershed's intensity-time-of-concentration relationships as obtained from an analysis of topographic data.

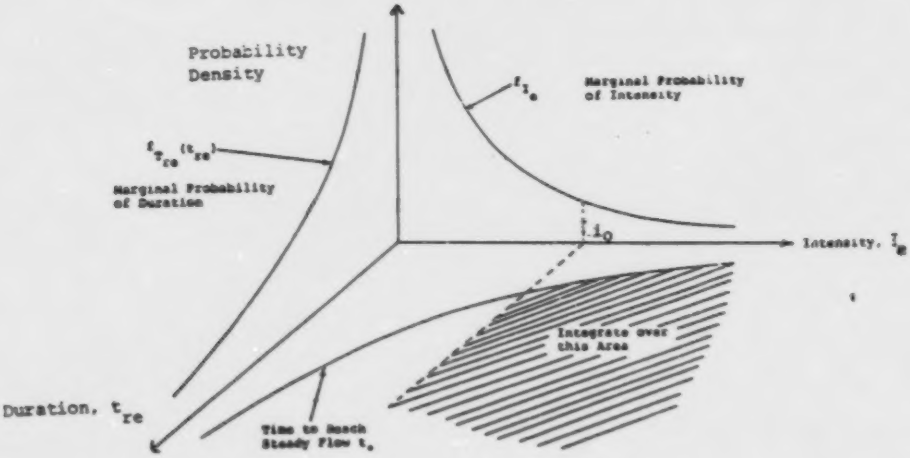

Probability Density
f_{I_e}
Marginal Probability of Intensity
$f_{T_{re}}(t_{re})$
Marginal Probability of Duration
i_o
Intensity, $\bar{I}_e$
Integrate over this Area
Duration, t_{re}
Time to Reach Steady Flow t_e

Figure 3.7 JOINT PROBABILITY FUNCTION

For flood probability calculation we must integrate over limits to the probability volume to the right of i_o and to the left of the steady flow curve. This gives probability of events for the steady flow curve, for which $i_e > i_o$ and $t_{re} > t$. The desired probability is then:

$$\text{Prob } \{Q_p \geq Q_o\} = \int_{\bar{i}_e = \frac{Q_o}{645A_r}}^{\infty} \int_{t_{re} = t_*(\bar{i}_e)}^{\infty} \lambda\beta e^{-\beta\bar{i}_e - \lambda t} \, dtdi \qquad (3.23)$$

integrating over t and using "a" and "b" as defined by Equations 3.16 and 3.17.

$$\text{Prob } \{Q_p \geq Q_o\} = \int_{i_o = \frac{Q_o}{645A_r}}^{i_e = \infty} \beta \exp \{\beta - i_e - \lambda(\frac{a}{i_e^{1/2}} + \frac{b}{i_e^{1/3}})\} \, di_e \qquad (3.24)$$

Note that the probability of the flood peak depends on the probability of the intensity, as expressed by β, the duration, as expressed by λ, and the watershed and stream characteristics as expressed by "a" and "b".

The integral of Equation 3.24 can be evaluated numerically, on a programmable hand calculator or mini-computer; it can be approximated by power series; or it can be fitted by another function which is integrable. IMP includes the numerical integration based on Simpson's Rule.

Another approach is to develop a solution which, although strictly speaking is incorrect, is in mathematical closed form and therefore more useful for many purposes. The approach is to incorrectly integrate Equation (3.23) by ignoring the dependence of t on i_e during the integration, accounting for i_e when the limits are applied.

$$\text{Prob } |Q_p \geq Q_o| \simeq e^{-\beta\bar{i}_e \quad -\lambda t_*} \qquad (3.25)$$

Now substituting for i_e and t

$$\text{Prob } |Q_p \geq Q_o| \simeq \exp \; - \left\{\frac{\beta Q_o}{645A_r} + \lambda(t_c + t_s)\right\} \qquad (3.26)$$

and, from (3.16) and (3.17)

$$\text{Prob}\ \{Q_p \geq Q_o\} = \exp - \left\{ \frac{\beta Q_o}{645KA_r} + \lambda \left[0.914 \left(\frac{645A_r^2 n_c}{\sqrt{S_c} L_s Q_o} \right)^{1/2} + 0.13L_s \left(\frac{645P_s n_s^2}{S_s Q_o} \right)^{1/3} \right] \right\} \qquad (3.27)$$

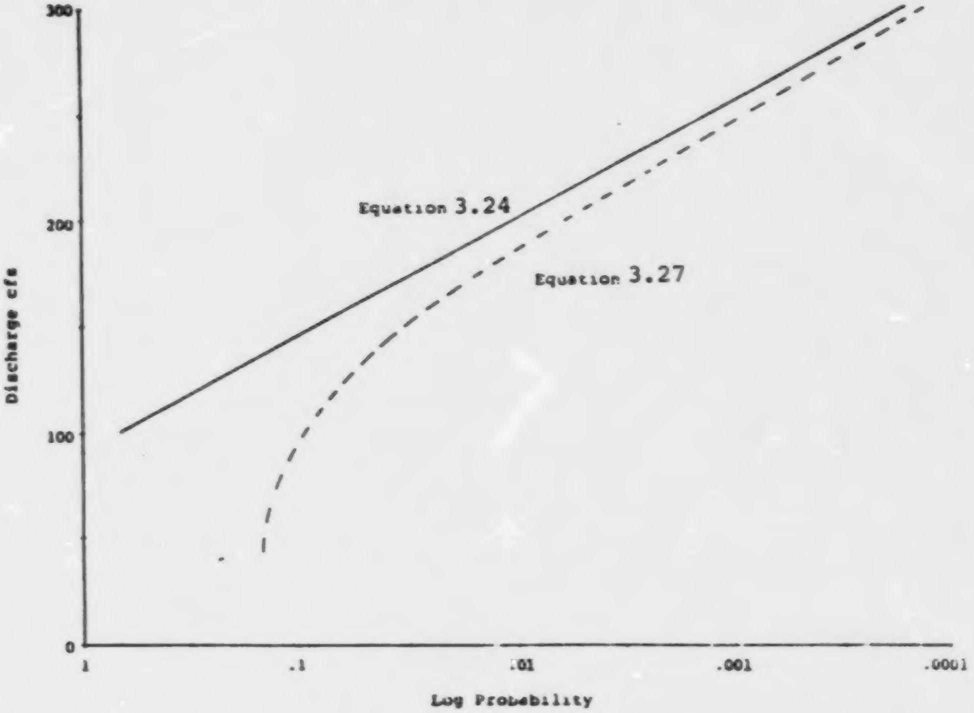


Figure 3.8 FLOOD FREQUENCY COMPARISON

Equation 3.27 is a good approximation to 3.24 for rare floods but drops off rapidly for more frequent floods, as illustrated in Figure 3.8.

3.8 Uses for Approximate Flood Frequency Formula

Equation 3.27 has the advantage of being easily solved on a hand calculator. It can also be differentiated to provide other equations for directly determining the importance of the various parameters on the flood frequency. A typical derivative of interest is:

$$\frac{\partial P}{\partial \beta} = \frac{Q_o}{645KA_r} E \qquad (3.28)$$

in which P is the probability that the discharge will exceed Q_o and E is the expression in braces in Equation (3.27). The sensitivity of the return period to errors in estimating the intensity parameter β is, therefore, dependent on the flood peak of interest, the watershed physiological parameters and the duration parameter, λ.

Other derivatives can be determined in an analogous way and a complete sensitivity analysis can be made available in analytic form. Such a result is of more practical value than Equation 3.24 which requires numerical integration to test sensitivity.

The approximate result of Equation 3.27 is also useful for estimating climatological parameters from known flood frequency curves. Such a procedure directly accounts for many uncertainties in estimating flood frequency curves for ungauged watersheds from data of nearby gauged watersheds.

Suppose that the parameters of interest are λ and β. The method is simple and may suggest other applications for such an approach. Equation 3.27 may be written twice using physiographic data for the gauged watershed and pairs of P and Q_o from its flood frequency curve. The two equations may then be solved simultaneously to provide calculated values of λ and β. These values may then be used to develop a flood frequency curve for the ungauged watershed.

There are two cautions:

1. The approximate flood frequency formula is a poor approximation for more frequent floods. The climatological parameters and should be calculated from pairs of rare floods of known probability - this may be impractical because of limited streamflow records.

2. Sensitivity analysis of Equation 3.27 shows that the equation is much more sensitive to β than to λ. When used in reverse, to estimate β and λ, small errors may result in ridiculous values of β while having little effect on λ. It may be more practical to guess at λ and solve only for β.

3.9 Evaluation of Flood Frequency Method

Peak flows can result from several types of climatological events interacting with properties of a watershed. The analysis presented here is intended to illustrate a systems analysis approach to obtaining practical results from what appears at first to be an unsolvable complex problem. A principal step involved discarding all runoff events for which steady flow was not achieved and/or for which the catchment response was slower than the stream response (t_s t_c situations were not evaluated). In reality there may be many circumstances in which such assumptions are not good. For these cases, another more appropriate procedure should be developed.

The method outlined here does not depend, in concept, on the exact relationships used to relate time of concentration to rainfall intensity. Other relationships, developed from complex hydrological modelling, or observed from actual data, may be used in place of Equations 3.16 and 3.17.

The joint probability density function for i_e and t_{re} was developed here from the independent marginal distributions of i_e and t_{re}. This procedure was possible because independence between these parameters was established statistically by the way in which events were defined. Hourly or daily rainfall totals can be used for this analysis depending on the watershed response. As discussed above, the watershed response should not be rapid enough to reflect variations in the rainfall which are masked by the reporting interval of the rainfall data. For example, if the watershed's time of concentration is close to the one-hour sample interval of hourly rainfall, it would be necessary to analyze rainfall data at shorter time intervals and/or to account for variations in rainfall during events which continue for several hours. The joint distribution would then need to be developed by direct enumeration of the data since independence assumptions would not be valid.

3.10 Estimates of Climatological Parameters

IMP contains a data base for annual average precipitation and 24-hour 10-year maximum rainfall. This data base cannot be used directly to estimate flood frequency because:

1. The resolution is too coarse for small watersheds that reach peak discharge in a few hours.

2. The data base provides no information about the probability distribution of rainfall duration or the annual number of rainfall events.

To overcome these deficiencies a correlation analysis was developed for parameters of the hourly rainfall data and the grid point values in the data base for several first order climate stations in B.C. The statistics of hourly rainfall time series were obtained from an intensive computer analysis of rainfall data tapes for the Environment Protection Service as part of an urban runoff control technology development project (Environment Canada, 1979).

Figures 3.9, 3.10 and 3.11 show the remarkably good relationships developed for the rainfall regimes of B.C., varying from less than 200 mm per year to more than 2000 mm. These relationships are programmed into **FFA**. The program uses the average annual precipitation estimate provided by **PRECIP** (adjusted for regional discrepancies in the Danard grid).

3.11 Estimates of Area Producing Runoff

The watershed modelling analysis discussed in the following Section provided insight into the flood behaviour of small streams in the various regions. It was found that the area producing floods varied from near zero in the driest region to the full catchment area in the humid coastal area. **FFA** estimates the ratio of the area producing flood runoff to the catchment area from:

$$A_r/A_c = \frac{\bar{P}}{3000}, \qquad \bar{P} \leq 3000 \text{ (mm)} \tag{3.29}$$

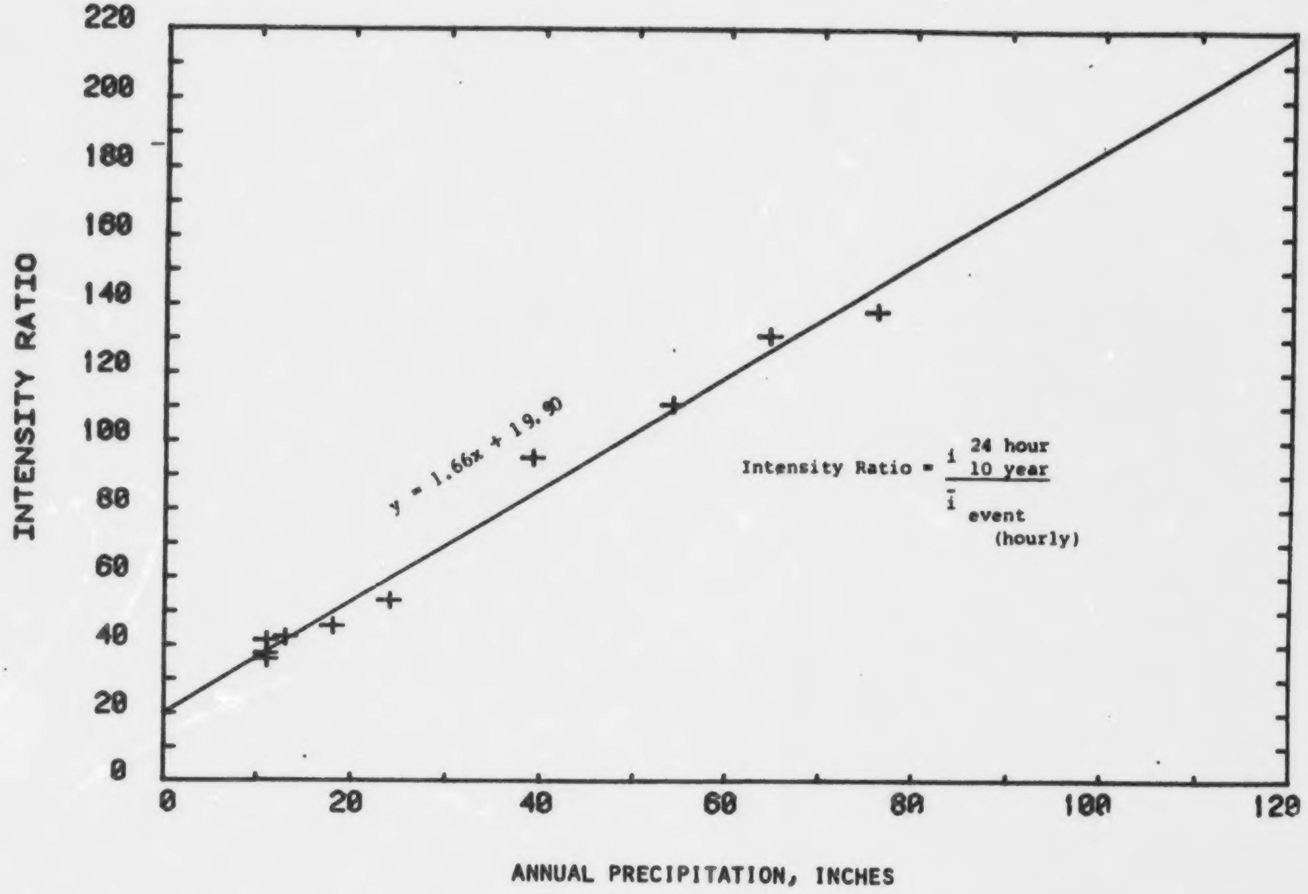


Figure 3.9 ESTIMATOR FOR RAINFALL EVENT INTENSITY

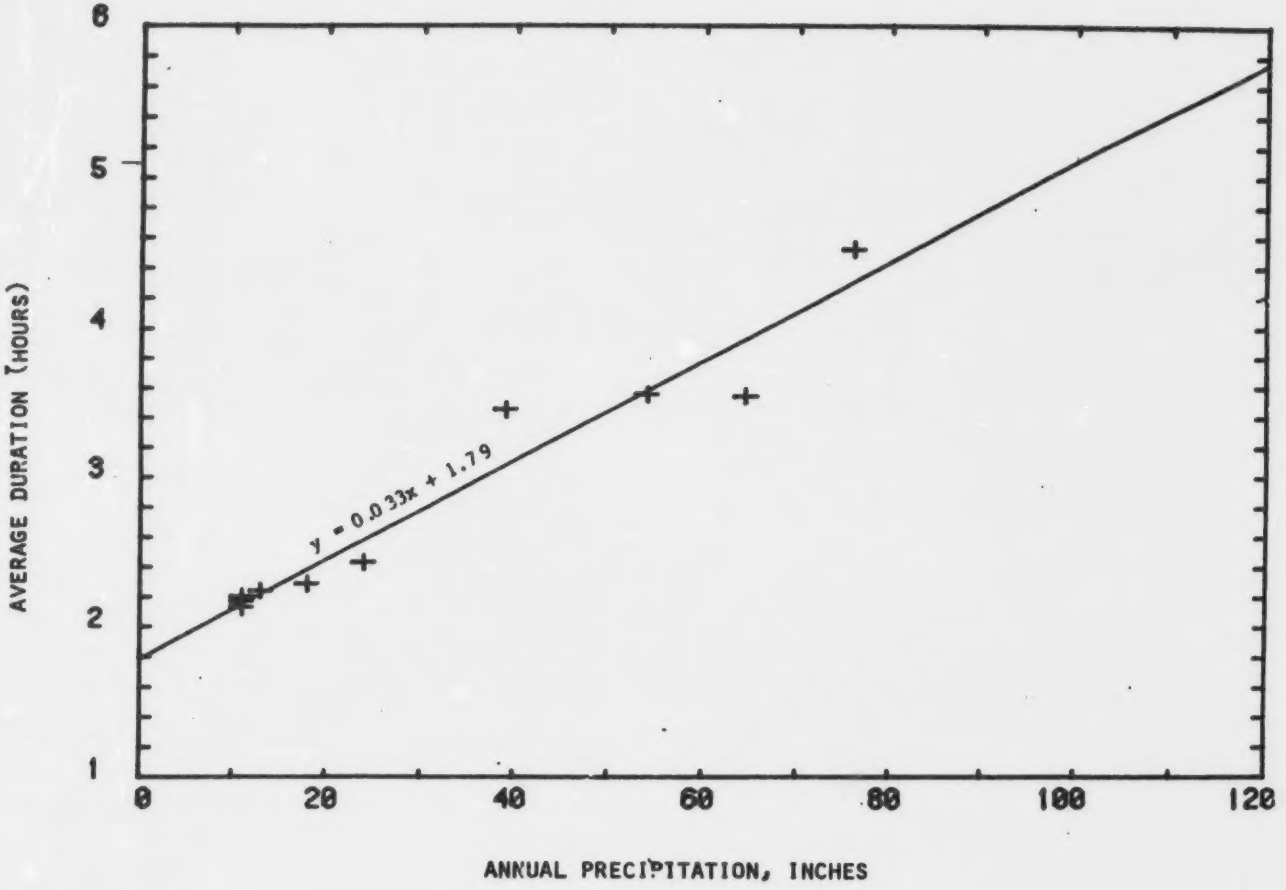


Figure 3.10 ESTIMATOR FOR RAINFALL EVENT DURATION

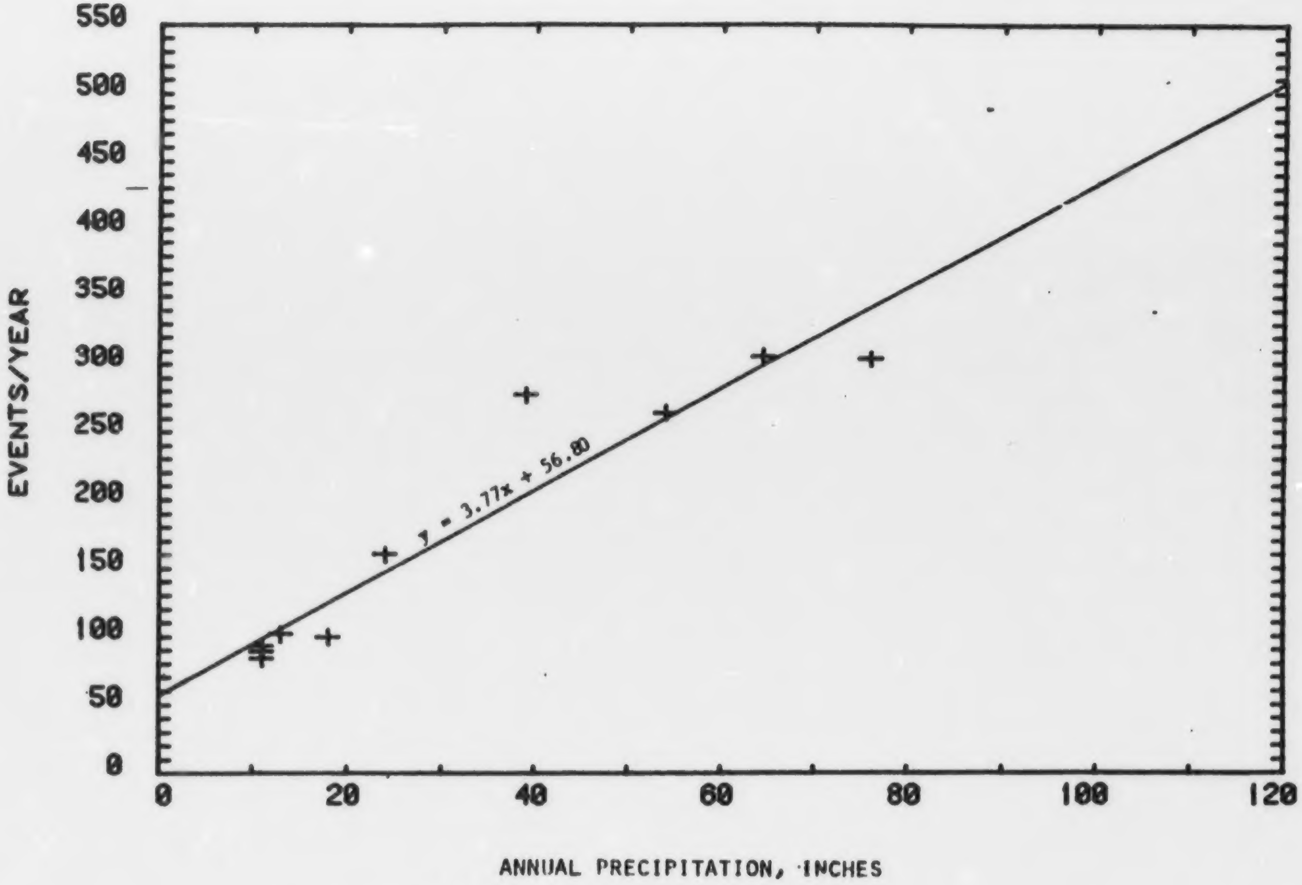


Figure 3.11 ESTIMATOR FOR NUMBER OF RAINFALL EVENTS

4.0 THE WATERSHED MODEL METHODOLOGY

This portion of **IMP** generates a time series of average daily runoff from a data series consisting of daily precipitation and daily maximum and minimum temperature. **IMP** contains this data base for fifteen years at one Atmospheric Environment Service (AES) station in each of the six regions of the Province. The watershed model assumes that these daily precipitation data can be realistically transposed to any watershed based simply on the ratio of the average annual precipitation at the hydro site to that at the AES station in the region and a lapse rate correction for the elevation difference. A paper by Quick and Pipes (1976) discusses the modelling approach, as follows:

The watershed model is based on the area-elevation characteristics of the watershed and utilizes relationships describing effects of lapse rates on precipitation. Watershed parameters were estimated from a study of the watershed response resulting from the rain and snowmelt inputs to gauged small watersheds.

A key aspect of the model is the division of the watershed into area-elevation bands. In mountainous regions, both precipitation and temperature are strongly elevation dependent, and in addition, many watershed characteristics such as soil characteristics, permeability, and groundwater storage can also be elevation dependent.

An important aspect of any watershed model is the stability of the calibration from year to year. For example, it is important to test whether flood and drought sequences can be correctly calculated with the same set of hydrologic parameters. Errors may arise from two primary sources. Firstly, there may be errors in the meteorological data inputs, especially rainfall. Secondly, errors may result from incorrect description of watershed behaviour, for example, incorrect allocations to the fast and slow runoff components. Behaviour of the watershed model depends on the accuracy of meteorological inputs and stream flow outputs so it is only feasible to identify large and obvious errors in either streamflow or precipitation values. A common problem with rainfall is the correct evaluation of its areal distribution from point measurements.

An objective during calibration is to identify parameter values which can reproduce watershed behaviour on a continuous basis for a complete range of hydrologic conditions.

To achieve stability of this type for watershed parameters, the model must be physically realistic in its description of the interactions of the various phases of runoff. To test parameter stability, calibration of the wateshed model is carried out by operating continuously for a number of years of data so that snowpacks are accummulated by the model from the measured precipitation and from precipitation-elevation relationships.

The major control parameter in the model is the soil moisture deficit, although when extreme rain intensities occur, the surface infiltration capacity may also become important. Soil moisture deficit is used to control the amount of runoff which is released to fast, medium, and slow runoff. These components of runoff can be thought of as direct runoff, interflow, and groundwater flow, although there is probably no precise physical interpretation. The amount of soil moisture fluctuates with rain, snowmelt, and evapotranspiration.

The routing of the fast component of runoff to the stream system is accomplished using unit hydrograph convolution. The unit hydrograph ordinates are based on a cascade of linear reservoirs (Nash 1957). The medium component of runoff can be routed through an additional linear storage reservoir before being convoluted. The slow component is accumulated in a linear storage reservoir and is released slowly from groundwater to the stream as long-term recession flow. This method provides flexibility while maintaining simplicity in calibration by minimizing the number of parameters. More detailed information on the UBC watershed model procedure is provided by Quick and Pipes (1983), from which the following discussion has been abstracted:

4.1 UBC Watershed Model Meteorological Analysis

Meteorological data is available as point values at a given elevation in a watershed. Before watershed response calculations can be made, these meteorological data at a point must be distributed to the mid-elevation points of elevation bands.

4.1.1 Temperature Lapse Rate

Lapse rates are known to be quite variable, ranging from high values approximating the dry adiabatic lapse rate to low values representing inversion conditions. A complete and detailed representation of this lapse rate variability is not possible, but the main features of lapse rate can be represented as a function of daily temperature range.

The following major features of lapse rate variation are recognized in the temperature lapse rate algorithm:

1. During continuous rainstorm conditions the lapse rate will approximate the saturated adiabatic rate. Under these

conditions the daily temperature range will tend to be zero or very low.

2. Under clear sky, dry weather conditions, the lapse rate during the warm part of the day will tend to the dry adiabatic rate. During the night, under these clear sky conditions, radiation cooling will cause the temperatures to fall to the dew point temperature, and this is particularly true for a moist air mass. As a result, night-time lapse rates under clear skies will tend to be quite low, and at times even zero lapse rates will occur.

Based on these considerations, two lapse rates are specified in the model, one for the maximum temperature and one for the minimum temperature. The lapse rate is calculated for each day using the daily temperature range (diurnal range) as an index.

Maximum Temperature Lapse Rate - TXLAPS

$$TXLAPS = TZLAPS + (TLXM - TZLAPS) * TD/TERM \qquad (4.1)$$

Minimum Temperature Lapse Rate - TNLAPS

$$TNLAPS = TZLAPS - (TZLAPS - TLNM) * TD/TERM \qquad (4.2)$$

where:

TD = daily temperature range (TX-TN)

TZLAPS = TZ - (PP/PPM) * (TZ - TZP)

for the above,

PP = daily precipitation
TLXM = $10^{o}C/km$
TLNM = $0.5^{o}C/km$
TZ = $6.4^{o}C/km$, that is, a reference lapse rate for rain-free conditions
TZP = $3.2^{o}C/km$, that is, a reference lapse rate when PP > PPM
PPM = 10 mm/day

and the calibration parameter TERM equals the maximum temperature range under open sky conditions (selected from the data set (TX-TN)).

4.1.2 Precipitation Elevation Gradients

The enhancement of precipitation as a moist air mass is driven by wind across mountain barriers is called orographic precipitation. This is an important aspect of mountain watershed modelling.

Orographic precipitation is influenced by three main factors, the slope of the mountainside, the mountain barrier height and the stability of the air mass. Precipitation distribution in **BCSIM** was modified for the **IMP** package, and is based upon a single precipitation gradient and on estimates of average basin precipitation developed from the **PRECIP** data base. For completeness, however, all of the precipitation distribution concepts included with the UBC Watershed model are reviewed in Section 4.1.2 to 4.1.5.

The stability of the air mass depends on the relative values of the saturated adiabatic lapse rate and the prevailing lapse rate of the surrounding air mass. A useful index of stability can be developed by comparing the values of the saturated and dry adiabatic lapse rates. The saturated adiabatic lapse rate depends on temperature being considerably less than the dry adiabatic rate when temperatures are high, but increasing to values similar to the dry adiabatic rate when temperatures are low. This variation of saturated adiabatic lapse rate will be used to account for the variation in orographic precipitation influences between winter snowfall, which shows a high orographic increase and warm summer rain which is relatively insensitive to orographic effects. Two algorithms describe the variation of precipitation with elevation. The first describes the basic enhancement of precipitation with elevation barrier height if the temperature is 32°F, and the second modifies this basic distribution for variations in temperature.

4.1.3 Orographic Enhancement as Function of Elevation, Barrier Height and Temperature

The precipitation in any elevation band is calculated from the precipitation at the AES station (PAES) using the equation

$$P_{J,L} = PAES * (1 + \infty) \qquad (4.3)$$

where:

$P_{J,L}$ = is the precipitation derived from the AES station precipitation for day J and elevation band L.

∞ = the precipitation enhancement factor defined in **BCSIM** as 4.7 percent per 100 metres.

Note that the $(1+\infty)$ multiplier produces a logarithmic increase in precipitation with elevation.

4.1.4 Form of Precipitation

The model must distinguish between precipitation in the form of snow and precipitation falling as rain, and this distinction must be made for each elevation band. Snow is stored until melted whereas rain is immediately processed by the soil moisture model.

The form of precipitation is controlled by the mean daily temperature in each band.

If $T < 0^{\circ}C$ all precipitation is SNOW
If $T > 2^{\circ}$ all precipitation is RAIN.

Between $0^{\circ}C$ and 2° a proportion of the precipitation will be specified as rain, and this proportion is defined by FORMPP where,

$$\mathrm{FORMPP} = \frac{T}{2} \tag{4.4}$$

Then rain, RN = PP* FORMPP, and snow, SN = PP* (1-FORMPP)

4.1.5 Precipitation Transposition Factors

Each meteorological station has two precipitation transposition factors associated with it, one for snow, SNOREP, and one for rain, RANREP. These factors are introduced because precipitation measured at a point is not always representative of the areal distribution of precipitation. For example, a meteorological station may be in a rain shadow situation, or it may be in a narrow valley where it is receiving precipitation which is more representative of the mountain side some hundreds of meters higher than the station. These transposition factors can be determined by comparing long term volumes of runoff with computed values.

In general, snow measurements are more likely to be distorted by local exposure and orography. As temperatures rise, rain values tend to be more representative because warm rain tends to be more convective in origin. When temperatures are above $18^{\circ}C$, the local convective nature of the rain makes it more reasonable to introduce an area reduction factor. The program logic is:

If TX < 0 use SNOREP
If 0 < TX < TRFORM, use linear interpolation between SNOREP and RANREP. (4.5)

4.1.6 Evaporation

Evaporation estimation in **BCSIM** can be subdivided into three processes. In the first process, estimates are made of the daily potential evapotranspiration (EVAP) for the reference (AES) meteorological station. In the second process, this EVAP value is distributed to each elevation mid-band level and is designated by potential evapotranspiration (PET). In the third process, these PET values are used in conjunction with the calculated soil moisture deficit values to yield an actual evapotranspiration value for each band (AET) and will be discussed in section 4.2.

$$EVAP = K * MK * TX \tag{4.6}$$

where:

K = an evaporation constant = 0.133
MK = a factor which is specified as a monthly factor. It accounts for the seasonal variation of EVAP

$$PET(L) = EVAP - 0.90 * ELD \tag{4.7}$$

where ELD is the elevation range between band elevation and the AES elevation.

For coastal regions **BCSIM** adjusts for Douglas Fir forests as follows:

$$PET(L) = PET(L) * (1 + 0.5*TREE) \tag{4.8}$$

where TREE = fraction of tree covered area. For interior forest Equation 4.8 is not used.

4.2 Soil Moisture and Groundwater

The daily amounts of snowmelt and rain are subject to various delays and losses before eventually appearing as river flow at some watershed outflow point. **BCSIM** contains certain logical statements which decide how these snowmelt and rain inputs are subdivided between evaporation loss, and fast, medium, slow and very slow runoff.

The central control parameter for the subdivision of total watershed input is the soil moisture deficit. Rather than attempting to specify a total soil moisture capacity, the model operates from a lack of soil moisture. When this soil moisture deficit reaches zero, the watershed reaches its maximum runoff potential.

The soil moisture model priorities for allocating runoff are described below.

4.2.1 First Priority: Impermeable Percentage - Fast Runoff Control

Part of each elevation band can be specified to be impermeable, so that any input of water to this area will enter the fast runoff component. Such runoff can be thought of in terms of surface runoff or very superficial percolation through coarse sediments. Such areas are usually riparian in nature.

The impermeable percentage of the watershed can be made to vary with soil moisture deficit. The algorithm in **BCSIM** which describes this process is:

$$\text{Impermeable fraction} = MXIMP * 10 ** (-BSD/AREGEN) \qquad (4.9)$$

where:

MXIMP = the maximum impermeable fraction when the soil is fully saturated.
BSD = is the soil moisture deficit in an elevation band.
AREGEN = is a constant which regulates how sensitive the impermeable area is to changes in soil moisture.

4.2.2 Second Priority: Soil Moisture and Actual Evapotranspiration

Before any further runoff can occur, other than fast runoff, the soil moisture deficit must be satisfied. While soil moisture deficits are being satisfied by incoming water from snowmelt and rain, there is also an evaporative demand which is continually building up a deficit.

Potential evapotranspiration has been described earlier. On any given day, in any given elevation band, there will exist a specified potential evapotranspiration. The soil moisture deficit which exists in that band will represent the actual evapotranspiration capability of that band. The **BCSIM** algorithm describing this relationship is:

$$AET = PET * 10 ** (-BSD/AETGEN) \qquad (4.10)$$

where:

AET = the actual evapotranspiration
PET = the potential evapotranspiration

BSD = the current value of the band soil moisture deficit.
AETGEN = a specified constant which controls the rate at which BSD influences PET.

This actual evapotranspiration demand will influence the area of the watershed which is permeable.

For each day a new value of soil moisture deficit is computed

$$\text{New value of BSD} = \text{BSD}-\text{PRN}-\text{BM}+\text{AET} \tag{4.11}$$

where:

PRN = rain input
BM = snowmelt input

If the band soil moisture deficit reaches zero, any excess water inputs can be subjected to further priorities.

4.2.3 Third Priority: Groundwater Percolation (GWPERC)

Groundwater percolation accepts any water excess up to a fixed limit (GWPERC). Any excess above this limit goes to a fourth priority, medium runoff.

Water which percolates to groundwater is assumed to be divided into specifiable fractions which go to the two groundwater components, the upper groundwater zone and the deep groundwater zone. This subdivision of groundwater is controlled by DZSHRE, the deep zone share.

$$\begin{aligned} \text{Upper groundwater zone recharge} &= (1-\text{DZSHRE}) * \text{GWPERC} \\ \text{Deep groundwater zone recharge} &= \text{DZSHRE} * \text{GWPERC} \end{aligned} \tag{4.12}$$

4.2.4 Fourth Priority: Medium Runoff

Any excess moisture input now remaining is assigned to medium runoff, or interflow. Although this is the lowest priority, it is frequently a most significant runoff component during active snowmelt and rain storms.

In the model, interflow is considered to be a large reservoir which receives inflows day by day during active snowmelt and rain. These inflows are the excesses remaining after satisfying soil moisture and groundwater abstractions. This reservoir releases a certain fraction each day, but the volume of water released does not immediately appear in the downstream channel system. Instead, this released water undergoes a convolution very similar to the fast component unit hydrograph. This release from an interflow storage reservoir and convolution before reaching the channel outflow point, produces a much more sluggish response for this medium runoff component.

4.3 Watershed Routing

Water allocated to each of the components of runoff, namely fast, medium, slow and very slow components, are subjected to a routing procedure which produces a time distribution of runoff. The routing procedure for each component is based on the same underlying concept, namely the linear storage reservoir. The fast and medium components of runoff are subjected to a cascade of reservoirs which is essentially identical to unit hydrograph convolution. The slower components of runoff simply use a single linear reservoir, thus avoiding the necessity to convolute for the final outflow.

4.3.1 Fast Runoff Routing

The Watershed Model calculates unit hydrograph ordinates for convolution of fast runoff. The calculation is based on a conceptual model of the runoff process developed by Nash in which inflows are passed through a cascade of linear reservoirs. The resulting outflow at time t from a unit impulse of inflow is:

$$u(t) = \frac{1}{TK^n} \cdot \frac{t^{n-1}}{(n-1)!} \cdot e^{-t/TK} \tag{4.13}$$

where:

TK = the linear storage constant for each of the reservoirs in the cascade.
n = the number of linear reservoirs in the cascade (usually 2).
t = the time after the water input has occurred.

The Watershed Model uses the above equation to calculate unit hydrograph ordinates for each day.

Linear reservoir routing of the components of runoff is computed as follows:

First reservoir: $Q_1 = Q_1 + (1/(1+TK)) * (WB - Q_1)$

.
.
. ....etc.
.
.

mth reservoir: $Q_m = Q_m + (1/(1+TK)) * (Q_{m-1} - Q_m)$

where:

Q_m = outflow from the mth linear reservoir
TK = time constant of the linear reservoir
WB = water input to the first linear reservoir

4.3.2 Medium Runoff Routing

The medium speed runoff, often thought of as an interflow component, undergoes a two stage routing process. In the first stage the medium runoff for each day enters a linear storage reservoir with a release constant INTK. The daily release from this reservoir is therefore a constant percentage of the total storage on any given day. Such a release represents an exponential decay which is identical to Nash's result with the number of reservoirs equal to one.

$$QI = QI + (1/(1+INTK)) * (WI - QI) \qquad (4.14)$$

where WI = the water input to the interflow reservoir.

The daily release QI is then subjected to time distribution by convolution with a unit hydrograph which is similar to the fast unit hydrograph.

4.3.3 Slow Runoff Routing

The slow components of runoff, usually termed groundwater flow or base flow components, are divided by the soil moisture model logic into a slow upper-zone component and a very slow deep-zone component. Both of these groundwater components are routed using a single linear reservoir which accummulates each day's inflow and releases a fixed percentage of the total storage each day.

4.4 Snowmelt

4.4.1 Snowmelt Formulation

The simple degree-day method for the calculation of snowmelt based on mean daily temperature has been proved to be reasonably adequate at least for moderate melt rates, and this method has had wide use in many studies. However, there are certain conditions under which the simple method seriously underestimates the melt rate. These conditions are firstly when humidity is high and minimum temperatures are also high, and secondly when radiant energy input is at a high level and the minimum temperatures are also high. These conditions are the situations from which snowmelt floods arise and it is during these conditions that melt rates can approximately double.

There are three main sources of energy which produce snowmelt:

1. Air temperature producing convective heat transfer
2. Radiant energy, the net result of short and longwave exchange
3. Condensation or evaporation on the snow surface and the resulting latent heat release.

The total energy resulting from these sources can produce snowmelt or sublimation. A crucial consideration is to determine how much of this energy input produces melt and how much produces sublimation. This partition of the energy input is controlled by the air vapour pressure compared with the vapour pressure of the snow surface, which explains why little melt occurs when air temperatures are low, even if there is considerable radiant energy, because cold air has a low vapour pressure.

In most hydrological situations there is insufficient data to define the net radiant energy exchange. Vapour pressure may be recorded, usually as a dew point temperature. The more complex melt equations such as the U.S. Corps equations attempt to evaluate the three separate components of convective heat transfer, net radiant energy and vapour exchange, but these equations appear to ignore the partitioning of energy between melt and sublimation.

A simple melt formulation, based entirely on air temperatures, has been set up in the following manner. Convective heat transfer is represented by the mean daily temperature above freezing. This term requires no further adjustment - if the mean temperature is equal to or les than freezing, then no convective melt will occur. The net radiant energy is represented in **BCSIM** by the daily temperature range, namely the maximum daily temperature minus the minimum daily temperature. But this term will only produce melt if the minimum temperature is above freezing. The underlying assumption here is that the minimum temperature is a good estimate of the dew point and so represents the vapour pressure relative to that of the snow surface. The -minimum temperature is used as a linear switch, or multiplier, and controls how much of the radiant energy contributes to snowmelt and how much produces sublimation.

The third important energy source or sink is condensation to or evaporation from the snowpack. This term is controlled by vapour pressure of the air compared with the vapour pressure of the snow surface. Again the minimum temperture is used as an estimate of dew point. The rate of condensation is determined by multiplying the dew point above 0°C by the linear multiplier based on minimum temperature.

The resulting snowmelt formulation is specified in two different forms, the first for forested areas of the catchment and the second for open areas.

4.4.2 Forested Melt Formulation

$$\text{Band Melt BM} = (TM + TCEADJ * (\frac{TD}{XTDIUN})) * PTM \tag{4.15}$$

where:

BM = Band melt for a particular band mid-elevation
PTM = Point melt factor
TM = Mean daily temperature of the band
TCEADJ = Energy partition multiplie, defined below
TD = Daily temperature range (TX-TN) in the band
TX = Band maximum daily temperature
TN = Band minimum daily temperature
XTDIUN = Radiant energy factor
TCEADJ = $\frac{TN + TD/XTDIUN}{XTDEWP + TD/XTDIUN} < 1$
XTDEWP = Reference dew point controlling energy partition between melt and sublimation.

Note that the TD/XTDIUN portion of the multiplier permits some radiation melt on days when TN is a little below freezing but the maximum temperature goes somewhat above freezing. Snowmelt BMR from rain is computed as follows:

$$BMR = K * TM * RN \tag{4.16}$$

where K = a constant, and RN = rainfall.

4.43 Open-Area Melt Formulation

This melt BMO above the tree-line and in open areas.

$$BMO = MMF * BM \tag{4.17}$$

where MMF is specified as a monthly factor.

In these open areas, the radiation component of melt is far more significant, so that melt is more dependent on the maximum daily temperatur than on the mean.

A similar open-area melt formulation is used for the melt, BMG of glaciers:

$$BMG = KG * BMO \tag{4.18}$$

where KG = a constant > 1.0.

4.4.4 Negative Melt Budget

If temperatures have been below freezing for any length of time, the snow becomes deeply frozen and requires ripening before melt can occur. These antecedent conditions are accounted for by keeping a running sum of antecedent mean temperatures, and allowing the total to decay by a certain fraction each day, specified by CCTK, the antecedent negative melt time constant. This decaying of the negative melt budget is essentially a "forgetting" process, so that the negative melt budget depends primarily on temperatures that have occurred over about the previous 10 days or so. The memory of earlier cold temperature decays away.

The ripening of the snowpack takes into account thermal input from rainfall, and further accounts for time delays induced by the water holding capacity of the snowpack. The ripening of the snowpack is computed as follows:

$$CC = CC + (1/(1+CCTK)) * (CCB - CC) \tag{4.19}$$

where:

CCB = TM + KCC*RN
CC = cold content storage
KCC = a constant.

The water holding capacity of the snowpack is expressed as a simple fraction of the cummulative snowfall.

4.5 Calibrations Considerations

The purpose of calibration is to define those relationships and concepts which cannot be quantified from known basic physical principles. Calibration also provides an opportunity to fine tune components of IMP based on actual experience with the procedures in British Columbia.

4.5.1 Regional Precipitation

The most sensitive factor affecting calculation of runoff from a drainage area is the knowledge of precipitation over the basin. Errors in estimates of basin precipitation will be directly reflected in comparisons of flow duration curves developed from simulation results and actual measurements. Initial tests with **IMP** revealed differences between the midrange of these curves and the need for adjustments in precipitation assumptions.

The regional validity of the **PRECIP** data base was examined by comparing long term, average precipitation records of the AES station network with long term average runoff records recorded by the WSC network of stream gauges. Differences reflect water losses from evapotranspiration and, on a unit area basis, this should be uniform within a given region of the Province.

Evapotranspiration varies throughout the Province from 300-400 mm in the interior to 500-700 mm on the coast even though precipitation ranges more widely from about 250 to 500 mm annually between these regions.

While large variations of runoff per unit area occur among watersheds in B.C. a large portion of this variation results from elevation differences and the consequent affect on precipitation. Representative hyposometric curves for each region were used to remove this source of variability and this made it possible to compare runoff and precipitation data on a consistent basis. (Runoff is also affected by evapotranspiration but, as discussed above, this factor does not have significant variability within a region of the Province).

This comparison showed that the spatial pattern of precipitation defined by the Danard grid correctly reflects the effects of topography but requires a scaling adjustment to bring the actual quantitative values into line with the AES/WSC data networks in areas away from the AES stations. This scaling factor was determined for each region by comparing Danard grid values with regionally representative values of precipitation developed from our analysis of the AES/WSC data for the region. Table 3.7 shows the specific values of average annual precipitation at the gauged watersheds in each region and the corresponding estimated adjustment factor which is representative for the region.

4.5.2 BCSIM Modelling Parameters

The UBC Watershed Model was developed as a research tool for testing the effects of hydrologic coefficients on basin yield and hydrograph shape. Although many of these processes and coefficients do no vary appreciably in nature it was informative to be able to examine them with this tool. For practical applications, as in **IMP**, many of the coefficients do not change. However a few need to be adjusted to reflect differences in hydrologic conditions among the six regions of the Province - these are the parameters which were calculated for **IMP**. The

Table 3.7 CALIBRATION FACTORS FOR REGIONAL PRECIPITATION

Region	Watershed Name	Annual Basin Precipitation (mm) WSC	DANARD	Recommended Adjustment Factor
1	Pallant	3760	1880	2.00
2	Carnation	3680	3200	1.15
3	Chapman	2980	2590	1.15
4	Pearson	724	483	1.50
5	McHale	1372	686	2.00
6	Cottonwood	1040	520	2.00

calibrated values were chosen with using the UBC Watershed Model in many past hydrology studies. Additional refinement to more exactly match simulation results to WSC data could be achieved for specific gauged watersheds within each region. This was not undertaken for **IMP** because it would involve a major hydrologic research effort to develop a significant improvement in the methodology designed here for analysis of ungauged watershed.

The values of the calibrated parameters defined in Table 3.8, which we recommend for use in the various regions, are shown in Table 3.9.

4.5.3 Runoff Area Contributing to Floods

The **FFA** model provides the capability to develop the relationship between average intensity and the time of concentration for ungauged watersheds. The use of this model in studies by B.C. Hydro for many small streams in the upper Columbia River basin has shown that the primary factor affecting time of concentration in the maintanence area of B.C. is the watershed area. For specific small gauged watersheds this knowledge was used to estimate the appropriate rainfall intensity from regionally representative intensity - duration - frequency curves developed by AES.

The WSC instantaneous peak flow data for many small watersheds was used to calculate the equivalent rainfall intensity i_{wsc} at specific return periods using the relationship:

$$i_{wsc} = \frac{Q_p}{645\ A_c} \tag{4.20}$$

with Q_p in cfs and A_c in sq. miles. The ratio of i_{wsc} to the intensity given by the AES intensity - duration - frequency curve at the appropriate time of concentration provided an estimate of the ratio of the area producing the flood runoff, A_r, and the measured area of the catchment, A_c.

Many values of A_r/A_c were examined and it was found that a good estimator is simply the mean annual precipitation. This result defined the following relationship which is incorporated into **FFA**

$$A_r/A_c = \frac{\overline{P}}{3000}, \qquad \overline{P} \leq 3000 \text{ (mm)} \tag{4.21}$$

in which the average annual precipitation $\overline{P}$ is in millimeters.

Table 3.8 - LIST OF WATERSHED MODEL PARAMETERS

Number of Bands	The number of elevation zones that represents the area vs. elevation distribution of the basin (hypsometric curve).
Elevation of AES station	Elevation of the AES meteorological station.
Precipitation Transposition	(Avg. precip. at hydro site / Avg. precip. at AES station) - 1.
Number of Sub-Basins	Defines the level of segregation in the basin
Mean Elevation of each Band	Mean elev. of each elevation zone (in meters).
Area of each Band	Area of each elevation zone in sq. km.
Tree Cover Fraction	Fraction of the area of each elevation zone that is tree covered. This parameter ranges from zero (no trees) to 1.0 (all heavily forested).
Glaciated Area	The area in sq. km. that is glaciated.
Impermeable Fraction of Area	Fraction of the land area of each elevation zone that acts as if it were impermeable.
Precipitation Adjustment Factors	Allows precip. input to be adjusted independently for each individual element.
Depressional Storage Allocation	Limits the runoff allocation to depressional storage. The fraction of fast and interflow runoff that bypasses the depressional storage reregulation (ranges from 0.1 to 1.0).

Table 3.8 - LIST OF WATERSHED MODEL PARAMETERS (Continued)

Fast Runoff Soil Moisture	- Provides a soil moisture deficit Deficit Control control over the fraction of runoff from each area element that is allocated to fast runoff (ranges from 50 to 300 mm).
Soil Moisture Loss Threshold	- Controls the relationship between actual and potential evapotranspiration. Actual evapotranspiration equals the potential evapotranspiration when the soil moisture deficit is zero.
Threshold Limit for Groundwater Allocation (in mm.)	- Establishes the daily threshold limit daily allocation to the groundwaterrunoff system.
Deep Zone Storage Allocation	- Establishes the proportion of the groundwater input allocated to the deepzonestorage.
Time Constant Fast Rainfall Runoff	- The linear reservoir time constant forfastrainfall runoff.
Time Constant Fast Snowmelt Runoff	- The linear reservoir time constant forfastRunoff snowmelt runoff.
Time Constant for Upper Groundwater	- The linear reservoir time constant for the upper groundwater component.
Time Constant Deep Zone Groundwater	- The linear reservoir time constant for deep zone groundwater component.
Outflow from Deep Zone Groundwater	- Initial value at beginning of simulation in cms.

Table 3.9 WATERSHED MODEL PARAMETER VALUES IN THE IMP DATA BASE

PARAMETER	I	II	III	IV	V	VI
No. of Bands	5	5	5	5	5	5
Elev. of AES station (m)	15	61	34	1250	1265	674
Precipitation Transposition	-0.275	0.157	0.343	-0.028	0.064	0.686
No. of Sub-basins	2	2	2	2	2	2
Mean Elev. of each Band (m)	30 110 230 380 600	100 150 230 370 630	290 620 850 1040 1200	1260 1350 1550 1670 1740	1270 1600 1850 2050 2300	1070 1250 1430 1620 1780
Area of each Band (sq. km.)	15.34	2.02	12.9	14.72	50.4	177.6
Tree Cover Fraction of each Band	.8	.8	.8	.8	.8	.8
Glaciated Area of each Band (sq.km.)	0	0	0	0	0	0
Impermeable Fraction Area of each Band	.1	.1	.1	.1	.1	.1
Precipitation Adjustment Factor for each Band	0	0	0	0	0	0
Depressional Storage Allocation	.3	1	1	1	1	1
Fast Runoff Soil Moisture Deficit Control (mm)	250	250	250	250	250	250

Table 3.9 **WATERSHED MODEL PARAMETER VALUES IN THE IMP DATA BASE** (Continued)

PARAMETER	REGION					
	I	II	III	IV	V	VI
Soil Moisture Loss Threshold (mm)	250	250	250	250	250	250
Threshold Limit for Groundwater Allocation (mm/d)	7	7	7	7	7	7
Deep Zone Storage Allocation	.5	.5	.5	.5	.5	.5
Time Constant for - Fast Rainfall Runoff (days)	.2	.1	.2	.2	.3	.5
- Fast Snowmelt Runoff (days)	.2	.1	.2	.2	.3	.5
- Upper Groundwater Component (days)	7	14	7	30	30	30
- Deep Zone Groundwater (days)	500	70	500	500	500	500
Outflow from Deep Zone Groundwater O-Storage (cms/d)	.910	.040	.350	.108	1.29	2.97

5.0 THE POWER STUDY METHODOLOGY USED IN POP

The purpose here is to describe how **POP** makes operational decisions from one day to the next, particularly if there is a reservoir involved. Unlike many simulation programs that use a series of ad hoc tests to determine operations **POP** is based on a well-defined mathematical structure. The advantages of this approach to simulation are:

1. Speed of execution is increased by minimizing the number of statements that must be executed.

2. The mathematical structure simplifies explanation of the program and makes it easy to modify the simulation algorithm to deal with additional reservoirs or complex connectivity among the individual reservoirs in a river basin.

The cornerstone of the simulation procedure is the operations research technique known as Linear Programming (LP) and it would be useful to be familiar with what this procedure does (as opposed to the mathematical details of how it works). The following sections should provide sufficient background information on LP for the purposes of this report. For a more detailed and easily understandable description of LP and its general application the reader is referred to the paper by Robert G. Blank (1981).

5.1 Linear Programming Approach

Linear Programming (LP) is a standardized method for optimizing a certain class of problem that has a linear structure. This structure is solved by a step-by-step, systematic, or "programmed" procedure. A linear programming problem is one in which the objective of the problem to be optimized, either maximized or minimized, is a linear sum of a set of decision variables, for example:

$$\text{maximize} \quad \Sigma_j c_j x_j \qquad (5.1)$$

The decision variables, x_j, are those parameters whose values are to be determined by the optimization procedure. The selection of the decision variable values that maximize the objective function is restricted to the set of decision variable values that are allowed by linear constraints of the form:

$$\Sigma_j a_{ij} x_j \leq b_j \qquad (5.2)$$

The decision variables must also be non-negative. The coefficients c_j, a_{ij} and b_j are all constants that are to be defined by the problem. The "less than or equal" relation can be "greater than or equal" or strictly "equal" as well. Any of these relationships are valid in constraints. All constraints together define the "feasible region" which is the set of all possible values of the decision variables that satisfy all constraints. The goal is to find the ones that maximize equation 5.1. There are standard methods and many computer programs are available for solving these problems. The details of the actual solution technique used in **POP** is therefore not described here.

Reservoir release decisions made by **POP** are structured in an LP formulation for each day with the objective of maximizing the total energy generated from the system of reservoirs. The version of **IMP** which accompanies this report contains a special adaptation of **POP** that will deal with only one reservoir.

5.2 The Objective Function

In a reservoir simulation model, the basic problem at each time step is to determine the controlled (powerhouse) release, the spill, and how much water should be left in storage. The release, Q, the spill, P, and the volume in storage, S, at the end of each day are the decision variables and the objective of maximizing energy at each time step is expressed as:

$$\max\ (b Q + C P) \tag{5.3}$$

in which b and C are coefficients with values proportional to their contribution to the total system energy.

The coefficient b on the release is calculated from the efficiency, n, and net head, H, on the reservoir so that in the objective function, the term,

$$b Q = n H Q \tag{5.4}$$

is the energy produced by the release. Spills of course do not produce energy and are a waste of water, and should be avoided. Therefore the coefficient, C, is set to a large negative number. This will ensure that the spill, P, will be zero unless it is absolutely necessary - when the reservoir is full and the controlled release is at capacity.

Equation 5.3 is the objective function used in **POP**. It has the same form as 5.1, a maximization of a sum of decision variables multiplied by coefficients which are updated each day. The LP is solved to determine S, Q, and P for the current time step such that the total energy is maximized.

5.3 Constraints

The constraints include , the continuity equation for the reservoir, the capacity of the facilities,and the operational rules. All of these considerations are structured in the form of Equation 5.2.

The continuity constraints are of the form:

$$S + \ t\ Q + \ t\ P = S^{t-1} + I \qquad (5.5)$$

where the time step t, the storage, S^{t-1}, at the beginning of the time step, and the upstream inflow, I, are all known for the current day from the results of the previous day. The values of the decision variables, S, Q, and P will maximize the objective function and satisfy this continuity equation. The inflow includes the local runoff into the reservoir.

The capacity constraints establish the size of the physical components. Capacity constraints have the form:

$$Q <= QCAP \qquad (5.6)$$

which simply states that the controlled release must be less than or equal to the maximum controlled discharge capacity. This is governed by the rating curve of either the penstock or the turbine set, whichever is less.

A similar constraint applies to the storage decision variable:

$$S <= SMAX \qquad (5.7)$$

where SMAX is the live storage volume of the reservoir and S is the volume in storage at a particular time.

Additional constraints must be specified to control the seasonal operation in a realistic manner. These are specified for each month and although this may result in a discontinuity in daily operations at months'-end it provides a convenient compromise between high resolution and simplicity in the model. The additional constraints deal with the following controls on reservoir and powerhouse operations:

1. Monthly maximum reservoir levels (i.e., for flood control).

2. Monthly maximum controlled releases through the powerhouse (i.e. for scheduled unit maintenance).

3. Monthly target minimum reservoir levels.

4. Monthly target controlled releases (i.e., to shape generation to the load pattern).

The targets impose a special set of constraints on the system. Here,

$$Q >= Q^T \tag{5.8}$$

and,

$$S >= S^T \tag{5.9}$$

where Q^T and S^T are the targets for each reservoir for the particular month. Note that these constraints are of the "greater or equal" type. Thus, while the energy is to be maximized the reservoir is not to be drawn below S^T and the controlled release is not to be less than Q^T. Selection of these values controls how the project is to be operated.

It is possible to set the targets so high that there is no possible combination of decision variables that will satisfy all of the constraints. For example there may not be enough water available at a particular time to meet all of the demands for it. If this occurs POP will automatically redefine the constraints to makea feasible solution possible. If Q^T 0, **POP** drops the constraint on reservoir levels (Equation 5.9), and at the same time changes 5.8 to:

$$Q <= Q^T \tag{5.10}$$

This will guarantee a solution but will limit the controlled release to the targets rather than exceeding them. However, if the targets are set to zero POP does not make these changes and Equations 4.8 and 4.9 continue to apply. If you are having difficulty in obtaining good operations from your choice of these targets it is usually a good idea to set them to zero. This gives **POP** a larger feasible region in which to develop the solution.

5.4 Operating Rules

The target minimum reservoir elevations (month and storage levels) in each reservoir and the target controlled releases for each reservoir are the essential elements in the reservoir operating scheme in the **POP** simulation model. These two parameters are interrelated and should be developed with this in mind. The amount of water that can be released on any day depends upon the water available in storage and the inflow. The two targets can be in conflict if there is not enough water to satisfy both. If the target release is too high then it may not be possible to meet the target reservoir level. Workable combinations of the two targets is dependent on hydrology and the live storage volume and how it will be used to regulate the flow. Appropriate targets will develop as the user gains experience modelling the project under study. In this section, some suggestions are made for developing a trial set of targets.

The basic purpose of a large storage reservoir is to store water from the wet season for use in the dry season. Using this simple concept, a hand calculation of the reservoir routing of the annual hydrograph of mean monthly flows gives a good indication of what the appropriate targets should be. The year can be divided into wet and dry seasons based on whether or not the monthly average flow is above or below the annual average (see Figure 2.3). Compute the average flow for the dry season and add the amount of live storage in the reservoir to obtain the desired dry season average flow by augmentation from storage. This proves a good starting estimate of the target controlled release for the dry season. Note that the target controlled release should never be more than the the annual average runoff otherwise over-year storage is used continuously and this will eventually cause the reservoir to empty and never refill.

The appropriate target minimum reservoir elevations can be determined from the volume of the target controlled release which must come out of storage in each month. Assume the reservoir is empty at the end of the dry season; then calculate backwards in time to determine the levels required at each month. A similar procedure can be used to develop the target minimum reservoir elevations during filling.

For reservoirs that are to operate run-of-river, a different approach is required. Basically, these reservoirs are always full and simply pass the inflow. Therefore, the target release would be the powerhouse capacity (provided that the penstock is large enough) and the target elevation is the full supply level throughout the year.

6.0 VERIFICATION OF IMP

6.1 PRECIP

On the west coast of Vancouver Island the AES station near Carnation Creek is located at longitude 125° 00' and latitude 48° 55'. For this location **PRECIP** shows the following values at surrounding grid points:

Latitude	mm
49° 00'	3378
48° 50'	3023

The interpolated value for the watershed is 3200 mm. Since the station is in Region 2, this value must be increased by 15 percent to account for regional discrepancies in the precipitation grid, yielding 3680 mm as the estimate for average annual precipitation (See table 3.7). For comparison the 1951-1980 AES data has a long term mean of 2770 mm, a discrepancy of 910 mm or about 28 percent. This type of error can be expected for the coastal area.

In Region 4 in the southern interior the AES station at McCulloch is located at longitude 119° 12' and latitude 49° 48'. **PRECIP** provides the following estimates for annual precipitation at surrounding grid points:

	119° 20'	**119° 10'**
49° 50'	356	660
49° 40'	356	737

At the AES station location the interpolated value of the annual precipitation is 611 mm. For Region 4 this must be increased by 50 percent (Table 3.7) yielding 916 mm as the estimated value for the AES station. The actual value given by the records is 664 mm, again showing a discrepancy which is about 28 percent high.

Both of these comparisons would superficially suggest that the regional adjustment factors of Table 3.7 are incorrect. However, the Water Survey of Canada records for Carnation Creek and (Pearson Creek, which is near the McCulloch AES station), must be considered as well. The WSC Carnation Creek data show that the annual runoff averages 2654 mm over the 10.1 sq. km. area. Within a few kilometers, the Sarita River data near Bamfield (124° 58', 48° 54', 162 sq. km.) has an annual runoff of 3932 mm. This watershed is only 2 minutes of longitude away from Carnation

Creek yet shows 48 percent more runoff - **PRECIP** estimates the annual precipitation to be 3154 mm, or almost the same as the Carnation AES station. Thus, if we directly compare the output from **PRECIP** with the WSC data from Sarita River we get runoff of 3932 mm from precipitation of only 3154 mm. Now, applying the Region 2 adjustment factor of 15 percent to the **PRECIP** estimate provides a value of 3627 mm, which is still less than the recorded runoff. This example serves to illustrate how difficult it is to accurately define local precipitation on small mountainous watersheds.

The situation in Region 4 is also difficult to assess. Near the McCulloch AES station there is a WSC gauge at Pearson Creek (119° 04', 49° 53', 73.6 sq. km.) and here the data show 423 mm of runoff. If you believe that the AES data is representative, this would indicate that water "losses" amount to 241 mm (about 36 percent) of the 664 mm recorded by the AES at McCulloch. On the other hand **PRECIP**, after applying the 50 percent Region 4 correction, indicates that the annual precipitation on the Pearson Creek watershed itself averages 724 mm. By comparison to the WSC data this suggests that the water "losses" amount to 301 mm, about 42 percent of the adjusted precipitation based on **PRECIP**, which is a reasonable estimate. Thus, **PRECIP** with the Region 4 correction factor probably is a reasonable tool for the Pearson Creek watershed, but for the AES location itself at McCulloch the regional factor is not required.

Examination of the **PRECIP** output (the Danard grid values) for interior locations suggests that other similar discrepancies may be contained in this data base. At many AES station locations there are local points of apparently anomalous high annual precipitation compared to values at the surrounding grid points. Examples include Barkerville (121° 31', 53° 04'), Glacier Rogers Pass (117° 31', 51° 17'), and Fernie (115° 03', 49°, 30'). These locations do not require application of the regional correction factor.

We conclude from our review of the available data that the regional precipitation adjustment factors of Table 3.7 should not be used in the close vicinity of the AES stations if the values from **PRECIP** appear to be much different from those in the surrounding grid. We also caution users of **PRECIP** that estimates of annual precipitation in coastal mountains may differ by 40 percent over very short distances within the grid cells.

The user is also reminded of potential problems with the grid data which result from uncertainties in the elevations at which precipitation values are reported (for more information, see discussion in Section IV).

6.2 FFA

Verification of the the Flood Frequency Analysis methodology is more complex because it involves consideration of the flood frequency modelling procedure as well as potential discrepancies in the precipitation data itself. The previous section pointed out how difficult it is to estimate average annual precipitation with confidence. For flood frequency analysis this difficulty is compounded by the need to know statistics of individual rainfall events. As discussed in 4, above, the small watersheds of interest here respond very quickly to rainfall and such statistics must be based on rainfall data which has been sampled hourly or more frequently. **IMP** contains internal routines based on our experience in other studies of the hydrology of British Columbia.

The rainfall statistics estimated by **IMP** are based on a detailed computer analysis of hourly averaged rainfall data over a period of about 15 years for ten stations in British Columbia. The routines in **IMP** incorporate our best judgment about how these statistics vary with average annual precipitation and the one in ten-year 24-hour maximum rainfall intensity grid developed by Danard. The rainfall statistic which has the greatest impact on the flood frequency curve is the average event intensity.

The discussion of the watershed model methodology in 4, above, describes how the area producing runoff differs from the area of the catchment measured from a topographic map. Again, **IMP** contains our best judgment about the variation of this ratio with average annual precipitation from place to place in the Province. The flood frequency curve is directly affected in proportion to changes in this ratio.

The watershed parameters which affect the shape of the hydrograph also have an influence on the flood frequency curve. These parameters determine the functional relationship between the time required for the hydrograph to reach its peak and the intensity of the rainfall. It is through the watershed routing effects that the rainfall duration probability distribution enters into the calculation of flood frequency. The time of concentration, the time to peak flow from the beginning of rainfall, is inversely proportional to rainfall intensity. Therefore, more frequent lower intensity events must endure for longer durations if the full potential effect is to be felt in the hydrograph. Thus, the watershed routing parameters primarily influence flood frequency curves at the lower end.

The above sets the stage for discussing specific comparisons between computed flood frequency curves and those obtained by plotting data from Water Survey of Canada records. We have selected three small watersheds for this comparison. Carnation Creek and Pallant Creek are located on the west coast.

Carnation is a very small watershed (10 sq. km.) located near Bamfield on Barkley Sound. It is located in modelling Region 2 where the precipitation adjustment factor is 1.15 and the average annual precipitation is 3680 mm as outlined in 6.1, above. The ten-year return period 24-hour maximum intensity given by **PRECIP** is 203 mm at this location.

Pallant is in the Queen Charlotte Islands at the top of Cumahewa Sound, near Aero. It is in Region 1 where the precipitation adjustment factor is 2.0 and the average annual precipitation averages 3680 mm. **PRECIP** suggests that the 24-hour ten-year maximum intensity is 205 mm here at longitude 132° 02', latitude 53° 03'.

Pearson is about 30 km east of Kelowna at longitude 119° 03', latitude 49° 53'. It is in Region 4 where the estimated annual average precipitation of 724 mm includes the 1.5 adjustment factor. The 24-hour value here is 31 mm, once in ten years.

Tables 3.10, 3.11 and 3.12 summarize the catchment and climatological parameters and shows the computed flood frequency curves produced by **FFA**.

The Water Survey of Canada provided flood frequency curves for these watersheds based on log Pearson Type III distribution parameters estimated by maximum likelihood. Tables 3.13 and 3.14 show values of daily maximum average flows extracted from these curves. We have also included the corresponding instantaneous peaks extracted from the published "Historical Streamflow Summary" and plotted at the same positions indicated by the WSC flood frequency curve. With this information we can compare the results obtained by **FFA** with flood frequency curves based on recorded instantaneous as well as the 24-hour average discharge.

Table 3.13 compares the results from **FFA** with the WSC data for Carnation and Pallant Creeks. Carnation Creek is much smaller and reaches a peak discharge in about 2 hours as shown on Table 3.10. The **FFA** results compare favourably with the daily WSC values but are much lower than those shown by the WSC data for instantaneous peaks.

The comparison for Pallant Creek is the opposite. On this larger watershed **FFA** compares reasonably well with the instantaneous flood peaks recorded by the WSC. As shown by Table 3.11 the time of concentration for this larger watershed is between .5 and 1 hour longer compared to Carnation Creek. As illustrated in Figure 3.2 the cut-off frequency for an appropriate

Table 3.10 FFA RESULTS FOR CARNATION CREEK

```
Catchment Name - CARNATION CR.

       Catchment Parameters

Basin Area                  10.1  sq.km.
Stream Length               5.8  km.
Stream Slope                .03
Manning's n for Stream      .05
Catchment Slope             .1
Manning's n for Catchment   .3
Stream Width                  4.0  m
Phi1 x Phi2                 .57
Ar/Ac                       1

       Climatological Parameters

                                            Rainfall      Snowmelt

Average Event Duration (hrs)                   6.594         0.000
Average Event Intensity (mm/hr)                0.780         0.000
Number of Events per year                    603.887         0.000




FLOOD FREQUENCY CURVE - CARNATION CR.

DISCHARGE  INTENSITY  TIME(HR)       RETURN PERIOD IN YEARS
  (cms)      (mm/hr) CONCENTRATION   RAINFALL  SNOWMELT  COMBINED
   12.01       4.28         2.8             1         0         1
   13.39       4.77         2.7             2         0         2
   14.77       5.27         2.6             4         0         4
   16.16       5.76         2.4             7         0         7
   17.54       6.25         2.4            12         0        12
   18.92       6.74         2.3            22         0        22
   20.30       7.24         2.2            42         0        42
   21.68       7.73         2.1            79         0        79
   23.06       8.22         2.1           149         0       149
   24.45       8.71         2.0           283         0       283
   25.83       9.21         2.0           551         0       551
   27.21       9.70         1.9          1115         0      1115
   28.59      10.19         1.9          2473         0      2473
   29.97      10.68         1.8          7094         0      7094
```

Table 3.11 FFA RESULTS FOR PALLANT CREEK

Catchment Name - PALLANT CR.

Catchment Parameters

Basin Area	76.7 sq.km.
Stream Length	10 km.
Stream Slope	.1
Manning's n for Stream	.05
Catchment Slope	.5
Manning's n for Catchment	.3
Stream Width	11.1 m
Phi1 x Phi2	.56
Ar/Ac	1

Climatological Parameters

	Rainfall	Snowmelt
Average Event Duration (hrs)	6.699	0.000
Average Event Intensity (mm/hr)	0.780	0.000
Number of Events per year	615.781	0.000

FLOOD FREQUENCY CURVE - PALLANT CR.

DISCHARGE (cms)	INTENSITY (mm/hr)	TIME(HR) CONCENTRATION	RETURN PERIOD IN YEARS RAINFALL	SNOWMELT	COMBINED
89.70	4.21	3.7	1	0	1
100.30	4.71	3.5	2	0	2
110.90	5.21	3.3	4	0	4
121.50	5.70	3.2	7	0	7
132.10	6.20	3.0	13	0	13
142.70	6.70	2.9	24	0	24
153.30	7.20	2.8	45	0	45
163.90	7.69	2.7	85	0	85
174.50	8.19	2.7	162	0	162
185.10	8.69	2.6	309	0	309
195.70	9.19	2.5	604	0	604
206.30	9.68	2.5	1228	0	1228
216.90	10.18	2.4	2731	0	2731
227.50	10.68	2.3	7859	0	7859

Table 3.12 FFA RESULTS FOR PEARSON CREEK

Catchment Name - PEARSON CR.

Catchment Parameters

Basin Area	73.6 sq.km.
Stream Length	15 km.
Stream Slope	.1
Manning's n for Stream	.05
Catchment Slope	.4
Manning's n for Catchment	.3
Stream Width	4.2 m
Phi1 x Phi2	.3
Ar/Ac	.25

Climatological Parameters

	Rainfall	Snowmelt
Average Event Duration (hrs)	2.735	0.000
Average Event Intensity (mm/hr)	0.500	0.000
Number of Events per year	164.434	0.000

FLOOD FREQUENCY CURVE - PEARSON CR.

DISCHARGE (cms)	INTENSITY (mm/hr)	TIME(HR) CONCENTRATION	RETURN PERIOD IN YEARS RAINFALL	SNOWMELT	COMBINED
7.67	1.50	3.4	1	0	1
9.35	1.83	3.1	2	0	2
11.02	2.16	2.9	4	0	4
12.70	2.49	2.7	7	0	7
14.38	2.81	2.6	13	0	13
16.06	3.14	2.5	25	0	25
17.73	3.47	2.3	46	0	46
19.41	3.80	2.3	87	0	87
21.09	4.13	2.2	166	0	166
22.77	4.45	2.1	319	0	319
24.45	4.78	2.0	626	0	626
26.12	5.11	2.0	1281	0	1281
27.80	5.44	1.9	2868	0	2868
29.48	5.77	1.9	8305	0	8305

Table 3.13 FLOOD FREQUENCY COMPARISON, REGION 1

Return Period Years	DISCHARGE (CMS) CARNATION CREEK (10 sq. km.) WSC Instantaneous	 Daily	 FFA	 PALLANT CREEK (77 sq. km.) WSC Instantaneous	 Daily	 FFA
2	30	13	13	60	40	100
10	57	20	17	100	70	126
50	80	27	21	130	93	155
100	90	30	21	150	110	165

Table 3.14 FLOOD FREQUENCY COMPARISON
Pearson Creek (74 sq. km.), Region 4

Return Period Years	Discharge (cms) WSC Instantaneous	 Daily	 FFA
2	12	8	9
10	16	12	14
50	19	14	18
100	20	15	20

representation of runoff in Carnation Creek is probably somewhat higher than it is for Pallant Creek. Thus, to estimate instantaneous peaks on Carnation Creek it is probably necessary to use a sample interval less than one hour. For Pallant Creek the one hour sample interval is reasonable. Thus, we draw the important conclusion that if **FFA** is to be used to estimate instantaneous flood peaks the time of concentration for the watershed should be at least three hours. This limitation is a result of the built-in routines that **FFA** uses to estimate the hourly rainfall statistics from average annual precipitation.

Table 3.14 provides the flood frequency comparison for Pearson, which is approximately the same size as Pallant Creek but it is located in Region 4. This region receives less precipitation than the coast and experiences a more continental climate including snow accumulation through the winter and a definite spring melt period.

FFA does a good job of estimating the flood frequency curve at Pearson Creek. The more frequent floods are underestimated, but this is to be expected because no provision has been made for snowmelt floods in the **FFA** example.

Comparison of hydrologic model results to actual streamflow measurements is always difficult because of the uncertainty in transposing precipitation data from a point source located some distance from the watershed to a basin average value. Eagleson (1971) provides a curve which purports to account for the effect of basin size on average precipitation, but this type of methodology is not recommended for use here with **FFA**. The precipitation transposition procedure described in Section 6.1 makes use of knowledge which is specific to the climate of British Columbia. While **FFA** is a compact mathematical procedure it is not entirely a black box. Results obtained with it can be interpreted somewhat based on an understanding of the physical factors influencing precipitation and runoff.

6.3 The Watershed Model, BCSIM

Verification of the streamflow simulation methodology is complex, and requires separate consideration of the use of the three **IMP** data bases:

- the **PRECIP** data base
- the AES temperature and precipitation times series
- the **IMP** watershed model calibration parameters

Errors in the estimation of the streamflow duration curve for an ungauged watershed may be caused by errors in the estimation of watershed precipitation, by errors in the estimation of watershed losses or by inaccurate representation of the effects of basin storage in transforming net inputs to streamflow.

The calibration parameters for the **IMP** project have evolved through years of testing and development of the UBC Watershed Model in Province-wide (B.C.) studies; they have not been developed by specifically fitting the daily data base provided with **IMP.** Many of the parameters have become less important as experience has improved the quality of the calibration (Section 4.5).

Standard functions have been used for estimating watershed snowmelt and loss (evapotranspiration), and a uniform local precipitation gradient has been used for all regions. Previous calibration work provided a consistent basis for determining soil moisture and groundwater control in the allocation of runoff components and the time distribution of runoff.

The methodology for determining synthetic flows has been sufficiently generalized that it should work equally well with daily temperature and precipitation data recorded at other AES stations in each climatic region. Where possible, the AES data selected for use with **IMP** was obtained from stations located at elevations within the mid-elevation range of the gauged drainage basins. Initial base flows do vary between the coastal and interior basins. However, the values used at each gauged basin correspond to the 2-year return period low flow on the coast and 1.4 times the 2-year return period low flow in the interior. Regional studies for low flow initialization have not been conducted, but the base flows specified for the gauged sites should be representative in each hydrologic region and used on a unit area basis for estimating initial flows in other ungauged basins.

Verification was carried out for the Carnation Creek watershed in Region 2 (Vancouver Island) and for the Pearson Creek watershed in Region 4 (southern B.C. interior).

BCSIM was used to generate synthetic streamflows for years of high, low and average runoff and **GAP** was then used to develop the flow duration curves. This analysis was carried out without reference to actual Water Survey of Canada data by simply using watershed model parameters developed from previous experience on other B.C. watersheds. The duration curves produced by the methodology were compared with the corresponding duration curves obtained from the gauged (WSC) records. Interpolation was used to estimate the streamflows corresponding to the 10, 30, 50, 70 and 90 percent cummulative probability levels. The actual streamflow hydrographs were also plotted using **GAP.** (Actual hydrograph simulations generally exhibit greater day-to-day discrepancies than those given by duration curves).

The verification results for the Carnation Creek watershed are summarized in Table 3.15. The verification results for the Pearson Creek watershed are given in Table 3.16. The results obtained for the coast region show that the discrepancies between the average annual **BCSIM** and gauged (WSC) streamflows are less than 10 percent. Duration curves of daily flow were also reproduced within 20 percent of gauged streamflows. This very high level of accuracy in reproducing the Carnation Creek hydrographs is exceptional and should not be expected in a consistent basic.

Another test of the reliability of the methodology on the coast is given by the results for the Pearson Creek watershed in the B.C. interior. For this interior basin, a discrepancy of 16 percent occurred in reproducing the average annual flow in the high runoff year. The flow duration curves were reproduced to within 20 to 40 percent.

This level of accuracy for Pearson Creek will not be obtainable in parts of the coast and interior where the local hydrology varies very significantly with distance and exposure. Furthermore, the reliability of the methodology will tend to deteriorate in very low runoff areas, in areas with high proportions of snowmelt runoff, and in areas significantly affected by river icing conditions in the winter.

The verification results in Table 3.15 and 3.16 are encouraging because they show that with good data the methodology will produce good results. The experience in developing **IMP** has confirmed the importance of site specific precipitation information when estimating runoff from ungauged watersheds in British Columbia. The knowledge base incorporated in **IMP** provides estimates of local precipitation and as future experience improves this knowledge base, the accuracy achievable by **IMP** will increase.

Table 3.15 RUNOFF VERIFICATION, CARNATION CREEK

Carnation Creek Streamflow (cms)

Year (Oct - Sept)	Average		Flow Duration (percent of time)									
			10		30		50		70		90	
	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP
High Runoff Year, 1975-1976	1.17	1.23	.087	.083	.21	.23	.41	.46	.94	.94	3.10	3.40
Average Runoff Year, 1981-1982	.85	.86	.020	.035	.08	.09	.24	.21	.60	.57	2.70	2.20
Low Runoff Year, 1978-1979	.53	.57	.052	.045	.10	.09	.15	.18	.37	.30	1.30	1.30

Table 3.16 RUNOFF VERIFICATION, PEARSON CREEK

Pearson Creek Design Flows

Year (Oct - Sept)	Average		Flow Duration (percent of time)									
			10		30		50		70		90	
	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP	WSC	IMP
High Runoff Year, 1975-1976	1.36	1.14	.075	.030	.11	.066	.21	.16	1.33	.83	4.75	3.10
Average Runoff Year, 1977-1978	1.00	0.97	.10	.08	.13	.10	.23	.25	.76	.65	3.20	3.10
Low Runoff Year, 1976-1977	0.76	0.71	.12	.08	.17	.10	.24	.17	.50	.33	2.60	1.80

INTEGRATED METHOD FOR POWER ANALYSIS (IMP)

SECTION 1V - IMP REVIEW WORKSHOP

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Appendix A - Workshop Agenda

Appendix B - Edited Workshop Transcript

1. INTRODUCTION

In July, 1987, the Department of Supply and Services, acting for Energy, Mines and Resources Canada, contracted with Charles Howard and Associates, Victoria, British Columbia, to conduct a peer review of an Integrated Method for Power Analysis (**IMP**). This is a package of microcomputer programs which had been developed previously for Energy, Mines and Resources Canada and Environment Canada to simluate the hydrology and to evaluate the energy potential of ungauged watersheds in British Columbia.

The purpose was to provide a review of the **IMP** package by a panel of experts with knowledge and experience in the practical problems of microhydro development. The experts were asked to evaluate the package on two sample projects furnished by Charles Howard and Associates, and on at least one other project of their choosing (preferably one that they had already worked on) so that effective comparison between the **IMP** microcomputer method, involving hydrologic simulation, and "conventional" analyses could be made.

Five consulting engineers were called together for a three-day workshop session. Each was experienced in estimating runoff from ungauged watersheds and in evaluating the potential for small hydro developments in British Columbia. Two of the consultants had previously used a mainframe version of the UBC Watershed Model, which is the hydrologic simulation component of **IMP**.

A worksbook was mailed to the consultants about two weeks prior to the workshop. This provided them with an advance opportunity to review the manuals, to run the computer programs, and to gain some understanding of the objectives for the workshop.

2. THE REVIEW

The review was held in the offices of Energy, Mines and Resources Canada, 100 West Pender Street, Vancouver, B.C., in two phases, the first of which was a two-day workshop on April 19-20, 1988 (see Workshop Agenda, Appendix A). Attendees at the workshop were:

Consultants Reviewing the **IMP** Package

Adrian Chantler, Crippen Consultants
Patrick Fawkes, Patrick Fawkes and Associates
Yaroslav Shumuk, Ker, Priestman & Associates Ltd.
John Knowles, UMAEngineering Ltd.
Dave Sellars, Klohn Leonoff Ltd.

Other Participants

Maurice Danard, Consulting Meteorologist
Charles D.D. Howard, Charles Howard & Associates Ltd.
Harry C. Torno, Charles Howard & Associates Ltd.
Tung Van Do, Charles Howard & Associates Ltd.
Roger Bryenton, Energy, Mines and Resources Canada,
Conservation and Renewable Energy Office
Neill Lyons, Environment Canada, Inland Waters Directorate

The peer review consultants were provided with basic training in how **IMP** works, and were than afforded the opportunity to go through two sample problems, one from the Chapman Creek watershed on Vancouver Island, and one from a watershed near Strathcona Lodge on Upper Campbell Lake, also on Vancouver Island. Six IBM personal computers were provided so that each of the experts could work independently. Dr. Maurice Danard, a consulting meteorologist who had developed the precipitation grid used in the **IMP** package, also gave a presentation explaining how that grid had been constructed.

After the workshop, the experts went back to their offices and completed the analysis on their own problem. A week later, on April 26, the group reconvened for one day to compare and discuss results, the benefits and drawbacks of using **IMP**, and recommended changes.

Upon completion of this second workshop session this report was prepared to summarize the discussions. A draft of the report was sent to the reviewers for editing/afterthoughts. This final version of the report includes changes recommended by them.

3. FINDINGS

This section summarizes the remarks made by the individual reviewers, as well as the salient points opf the general discussion which ensued. We have also included (Appendix B) an edited transcript of the actual discussions, taken from a tape recording made during the second workshop session on April 26, for amplification of this summary.

The reviewers found that the **IMP** package was a useful took for experienced hydrologists, but that some portions of the package were more useful than others. They all agreed that a major benefit of the package was that it made the UBC Watershed Model available to the general public for the first time. They believed that the hydroelectric power simulation program (**POP**) and the graphics analysis package (**GAP**) were powerful and useful aids to analysis. They were very critical of the Danard grid in the (**PRECIP**) Module primarily because, in the discussions with

Maurice Danard, it became apparent that the method used to construct the grid meant that the precipitation at each grid point was not necessarily the precipitation at the ground elevation of that point, but rather at some unknown elevation related to the elevation of the nearest AES gauging station(s) used in Danard's model. In addition, the Danard data base was taken from 1941 - 1970 data, rather than from the 1951 - 1980 data now available, and also had some highly suspect values, particularly in the northwestern part of the Province. The reviewers held the opinion that flood frequency analyses were better done using conventional regional analysis techniques, rather than by the **IMP** package's **FFA** module.

In the analysis of their own test problems, the reviewers had mixed results, which most attributed to deficiencies in the precipitation data base, or to the fact that their problem catchment was significantly different from the regional catchment upon which watershed model parameters are based.

John Knowles obtained satisfactory results from the watershed model (about 20% discrepancy between model simulations and data from nearby streams). The **POP** module calculated poer production about 0% higher than he expected. He pointed out the the **GAP** package is very good, and that it would be very useful to have tabular, as well as graphic, output.

Yaroslav Shumuk had a great deal of difficulty with the precipitation estimates from the Danard grid data, primarily because the reference elevation of the Danard data is unknown. He noted that the site he used for his test, in northwestern British Columbia near the town of Stewart, was a difficult one, because the gauged basins are very large and his site was on a very small watershed in a glaciated area at high altitude. It further appears that the Danard data could be faulty on the coast, since Danard did not do a maritime analysis in this part of the province. Mr. Shumuk noted that it would be advantageous, in cases like these, to be able to use precipitation data from one region, and temperature data from another. Mr. Shumuk found that the **POP** portion of the package worked well, but he was not comfortable with the theoretical basis for the flood frequency analysis (**FFA**) module.

Dave Sellars also had difficulties with the precipitation portion of the package, and noted that it might be necessary, in view of the difficulties with the Danard grid, to recalibrate the watershed model with "correct" precipitation values (we disagree with this, since the BC Watershed Model (**BCSIM**) was incorporated into the package by Mr. Tony Pipes using the Danard data with a good deal of testing and verification. Mr. Sellars used a test catchment in northwestern B.C., and had very good results. When he tried it on another catchment south of Kamloops, however, the computed flows were about 5 times larger than recorded flows. He concluded that the disagreement was due to differences between his catchment and the "regional" catchment included in the **IMP** package. He, therefore, concluded that if one is trying to model a catchment with the same climate and catchment characteristics as the regional catchment, then one will get good results. Mr. Sellars also suggested that data sets for years in which there is a significant amount of missing data should be deleted from the data base. A summary should be provided for each reference station of the data that is missing. (Mr. Howard noted at this point that the capability exists in the **IMP** package to use actual data of your own if it is available, and that the user should base his analysis on all available data, not just the six reference sets provided with **IMP**). Mr. Sellars noted that the **GAP** module is an important component, but it has a number of shortcomings, primarily in the way it generates summary information. He concluded that the **IMP** package should be used only by qualified hydrologists who have the experience to interpret the results.

Adrian Chantler began by noting that he was more comfortable approaching small hydro feasibility studies from a streamflow base rather than a precipitation base. He questioned the division of the province into six representative precipitation regions, suggesting that a finer subdivision would be more useful, and reiterated the comments of others about the inadequacies of the Danard grid. On his test catchments, the Kicking Horse River in southeastern B.C.,he found that the **FFA** module gave him results that were about 50% higher than his own flood frequency analysis based on Water Survey of Canada gauging data. On the other hand, he found that the mean annual discharges were about 50-60% lower than the gauge data. Mr. Chantler found the **POP** programs very useful. He concluded that he preferrred his regional hydrology approach to using the streamflow simulations in **IMP**.

Patrick Fawkes began by reiterating that the **IMP** package is not suitable for the non-technical person. He felt that it was important to add a "calibration" version of **BCSIM** to the **IMP** package, indlugin a built-in statistical package, similar to the one used on the mainframe version of the program he was familiar with. Mr. Fawkes noted that a user's manual for this version had been prepared for B.C. Hydro a number of years ago. (Mr. Howard pointed out that we had written a version of this calibration program which could be modified to do the statistical analyses). Mr. Fawkes felt that the **BCSIM** module should not be released as it is, because of the discrepancies between modelled and recorded flows. He used the **IMP** package on the Goat River area in the West Kottenays and found initially that his modelled flows were about one third of the measured flows. He attributed this to problems with the precipitation data. He was able to correct this by adjusting the precipitation, but was then not too confident in the results from **POP**.

There was some discussion of whether or not to include reservoir operation optimization routines in **POP**. Mr. Howard noted that we had done this in another context, using a commercial linear programming package, and that it provided signigicant advantages over using rule curves for reservoir operation. It is not, however, a trivial programming problem to add it to the **IMP** package. There was also some discussion of possible moodifications to **GAP**, including summary tables of relvant data.

There was general consensus that the Danard grid should be modified. Bad data should be eliminated, and there should be a separate grid provided showing the reference elevation of each data point on the Danard grid to allow the propoer precipitation adjustments to be made (or, alternatively, a grid with precipitation values which represent the precipitation at the ground elevation under each grid point). John Knowles also expressed the desire to have the entire precipitation input process be a part of the program - eliminating the current need to do some calculations by had.

The consultants concluded that the **IMP** package should be released for the use of engineers with experience in hydrology (with some modifications, including a "calibration" option). They further noted that the **BCSIM**, **POP**, and **GAP** portions of the package were the most useful, and they suggested that most experts would be more likely to use these models individually, rather than by running the **IMP** package as a whole.

4. RECOMMENDATIONS

In addition to the findings noted above , the consultants made a number of specific suggestions for improvement of the package. These are listed below, in no particular priority order. We have already taken appropriate action for those recommended changes marked with an asterisk (*).

1. Some data points, pariticularly in northwest B.C., should be eliminated from the Danard grid. (*)

2. Data points in the Danard grid should also indicate the elevation to which the data refers.

3. The Danard data base should be updated to use 1951-1980 data.

4. An advisory screen should be provided defining water year. The same sort of adivsory should be given on output. (*)

5. **GAP** should be able to print and/or display monthly means of precipitation, flow and power output.

6. Computer "beeps" should be eliminated. (*)

7. The units (energy/power) should be consistent in **POP**. (*)

8. Monthly means and annual summaries should be provided as an output option in **BCSIM**.

9. The program should allow use of non-integer values in **GAP**. (*)

10. There should be advisories in the program about missing data, and how it should be handled. These advisories should be a part of the data set. (*)

11. Costs of diesel makeup and the value of execess energy should be included in the economic analysis in **POP**.

12. The program should be clear when calling for the use of area or fraction. (*)

13. The bug in **BCSIM** relating to second and later year flows when the calibration option is being used should be corrected. (*)

14. There should be a calibration module provided for **BCSIM**, including the full statistical package which was used during calibration to compare computed daily flows with recorded flows.

15. The program should provide some advisory information on the screen with respect to handling deep-zone groundwater (initial estimates). (*)

16. The program should incorporate function keys tied to program macros to perform such functions as switching between foutines, printing graphs, etc.

17. The **IMP** package should be reorganized using the latest compiler - so that each unit can be a subroutine accessible from a single main menu.

18. The counter for sub-basins should be changed to reflect the actual number of sub-basins being considered. (*)

19. The color displays in **FFA** should be reviewed for more appropriate color choices (more contrast, use of colors that are easier to read). (*)

20. The turbine type should be displayed on each turbine efficiency curve. (*)

21. The capability should be added to provide automatic estimates of penstock size or flow (based on head and power desired).

22. The program should be changed to include more "normal" return periods in **FFA**, or to provide graphic flood frequency output.

23. The problem of loss of significant figures at very low flows should be corrected. (*)

24. The program should have the capability of choosing a temperature sequence from one AES station record, and a precipitation sequence from a different station

25. In the **GAP** program:

a. Monthly, annual or total summaries should be included as an option.

b. Some simple statistics should be available for the analysis of output.

c. A grid should be superimposed on plots.

26. The 10-year data limit on **POP** should be removed.

27. **POP** should be extended to energy cost analysis for various project lioves, discount rates, etc.

28. The output from **BCSIM** should indicate which input data set was used. (*)

29. **BCSIM** and **POP** should include screen advisory messages when computing (in some places the user can be confused about whether the program is actually doing something or has bombed out). (*)

30. **POP3** should include a routine to calculate $/CMS/YR.

31. The capability should be provided to prorate, by drainage area, .WSC or other data records. (*)

32. Confirmatory screen messages should be included whenever a file has been saved. (*)

We have also, at the request of the project officer, Mr. Roger Bryenton, made approximately 60 additional minor cosmetic changes to the program, and have furnished Mr. Bryenton with diskettes containing updated source and exectuable versions of the **IMP** package and with a set of updated data diskettes.

5. FUTURE MODIFICATIONS AND IMPROVEMENTS

As indicated in the previous section, there were a number of changes recommended by the reviewers, some of which have already been made, and others which are outside the scope of the present contract. In the latter category, probably the most important would be to restructure the program so that it will run as a single master program with a number of subroutines (this was not done originally because of the compiler limitations on the personal computer available at the time). This would increase program efficiency, reduce execution time, and make the **IMP** package easier to use. This restructuring should be accompanied by appropriate revisions to the **IMP** documentation.

Another major recommendation was that the Danard grid be revised to incorporate the 1951-1980 data, to provide suitable data for the portions of the Province not now covered in the data base, and to provide a suitable means of adjusting Danard grid data to local ground elevations (this last improvement will have to be accompanied by a recalibration of the **BCSIM** module to the revised data).

The reviewers also recommended that a calibration version of **BCSIM** be provided which includes the statistical analysis package developed for B.C. Hydro. This would provide a convenient tool for improving a user's confidence in the modelling results.

Other recommendations included:

1. Provide the capability for optimizing reservoir operation and power generation in the **POP** component of the **IMP** package.

2. Provide the capability to do calculations (like the interpolations between Danard grid points) on the screen, instead of longhand as required in the current version.

3. Provide, automatically, first estimates of penstock diameter/generating capacity from flow and head estimates.

4. Provide more flexibility, including variable time periods, in outputs from **GAP**.

In addition, Mr. Bryenton, who has probably used the **IMP** package more than anyone else, has suggested perhaps 100 or so other changes to the package.

We would be happy to make a proposal to make any or all of these changes. Some, at least, are included in work already proposed for Phases II and III of the current project (which have not yet been funded). Recent advances in microcomputer technology and reductions in hardware and software costs give us the potential to provide a system which would be even more compact and convenient for the user.

6. SUMMARY

The workshop was a very productive and effective method for reviewing the **IMP** package. It was apparent that the reviewers had put in a good deal of preparatory effort, and this allowed a much more intensive review than might otherwise have been possible. While there was considerable variability among the reviewers with respect to their experience and familiarity with microcomputers, this did not seem to be a particular problem in the conduct of the review. We did feel that there was too much emphasis placed on the inadequacies of the Danard grid. It is, after all, only an estimating technique, and engineering judgment must be applied in the same way that such judgment would be applied in a more traditional analysis.

APPENDIX A

IMP Review Workshop

Energy, Mines and Resources Canada
100 West Pender Street
Vancouver, B. C.
April 19-20 and April 26, 1988

AGENDA

Tuesday, April 19

9:00	Introduction to **IMP** and the Review	C. Howard R. Bryenton
9:30	**IMP** Package Overview	T. V. Do C. Howard
10:30	Sample Problem #1	Participants
12:00	Lunch	
1:30	Sample Prolem #1 (cont'd)	Participants
4:00	Sample Problem #2	Participants
5:00	Adjourn	

* * * * * * * * * * * * * * *

Wednesday, April 20

9:00	Sample Problem #2 (onct'd)	Participants
10:00	The atmospheric Database	M. Danard
12:00	Lunch	
1:30	Discussion	Participants
3:30	Individual Problem Setup	Participants
5:00	Adjourn	

Tuesday, April 26

9:00	Introduction	H. Torno
9:15	Presentation of Individual Critiques (15 minutes each)	Participants
10:30	General Discussion	Participants
12:00	Lunch	
1:30	General Discussion (cont'd)	Participants
5:00	Adjourn	

APPENDIX B

IMP Review Workshop - Edited Transcript

The following transcript was edited from a tape recording of the discussions which took place on the third day of the Workshop. The participants were:

Charles D.D. Howard (Chuck)	Charles Howard & Associates Ltd.
Harry C. Torno	Charles Howard & Associates Ltd.
Tung Van Do	Charles Howard & Associates Ltd.
John Knowles	UMA Engineering Ltd.
Adrian Chantler	Crippen Consultants
Yaroslav Shumuk	Ker, Priestman & Associates Ltd.
Dave Sellars	Klohn Leonoff Ltd.
Patrick Fawkes	Patrick Fawkes and Associates
Roger Bryenton	Energy, Mines & Resources Canada
R.O. (Neill) Lyons	Environment Canada

The first person to speak was John Knowles, UMA Engineering. (Because of problems with the microphone, the tape was not clear, so the following is not a transcript of his remarks, but rather a reconstruction from memory of what he said).

John obtained satisfactory results from the watershed model, experiencing about a 20% discrepancy between the computed mean annual runoff and the value estimated by comparison with records from nearby streams. However, POP, the program which performs the power study, calculated power production which was about 20% higher than he expected.

The program uses turbine efficiency curves which do not account for other sources of inefficiency and computer penstock head losses from actual flows each day. The earlier power study was based on average monthly flows and average losses and efficiency factors.

(From this point on, the transcript is edited directly from the tape recording).

The next review was by Yaroslav Shumuk of Ker, Priestman and Associates.

Yaroslav: "I applied the IMP package to a site in the northwest part of B.C. My experience was the opposite from John's. I had difficulty with the hydrologic part but I had relatively successful results on the power side. The very first thing I did, which was to call up PRECIP to come up with some values for average annual precipitation, gave me a very strange looking computer screen, and I have a copy of it here.

We were working in a location very close to the Alaska panhandle, down near the location of the Town of Stewart, B.C. Precipitation here is very high, in the order of 2100 mm per year. Immediately to the north, on the very next line, there is a drop to 610 and 635 mm, and to 0. Maurice Danard dropped in to see me and pointed out that the 0 values were supposed to be for areas in Alaska that were not included within the scope of his study. However, if you look closely you will see that some of these zeros fall in B.C., and unfortunately, in the area where we are working. This site is close to a value of 711 mm given by the precipitation grid.

Some time ago our firm did a regional hydrology study for this area. It is a very remote area with a sparse data base and the usual challenges, but there were enough indicators to develop some appreciation for the situation. From regional runoff and regional precipitation trends, snow course data in the region, and site specific accounts of how much snow usually accumulates before it starts melting, we were able to come up with an idea of what the winter precipitation might have been. Because we knew that a hydro site was going to be designed based on the data, I was careful to alert the designers that there is quite a bit of uncertainty in precipitation in this area. I gave them a low estimate of 1800 mm per year for the mean annual precipitation and a high estimate of 2500 mm. Those figures are for an elevation of approximately 4600 feet.

The grid in PRECIP gives a value of 711 mm somewhere around the elevation of the AES stations that were used in developing the grid. I assume that these were around sea level, although as our discussions last week showed, nobody actually knows for sure. But, even if you assume that sea level was used and apply the procedure in the manual, the result does not come close to the mean annual figure which I came up with by the more conventional method. I was stuck, for here I had some useful data for this site. I had an estimate which I thought was the best you could get (for the mean annual precipitation) and I couldn't put it into the model directly. There was no blank to fill in with say 1800 mm, or the average of 2150 mm to let the model come up with a precipitation transposition factor. That capability would have been quite a useful addition to the program.

The program prompts you for the mean elevation of the site and when you put that in it gives you a transposition factor. I presume that the elevation of the AES station which is supposed to be representative for the region is related to this transposition factor."

Chuck: "The precipitation grid information is totally unrelated to all other parts of the package. The value taken from the grid can be used in BCSIM or a value for long term average precipitation can be developed by any other method."

Yaroslav: "When I put that value, 2150 mm, into that slot in the program I get runoff values which are far too high. Maybe because I've given it the elevation of the AES station it is taking the 2150 mm and increasing it to account for the 4500 foot elevation of the site."
Roger: "Perhaps you should have taken it down to sea level before bringing it back up."

Yaroslav: "That's probably right. I ended up using a trial and error procedure and finally ended up with a number of about 1200 mm as the correct value for input to the program. This gave reasonable results. The precip transposition factor was worked out automatically based on TASU which is the AES site recommended for use in that region and that gave me mean annual runoff values which were close to those provided by the regional hydrology study.

This is a difficult area for regional hydrology because most of the basins that are gauged are very large, and the site is a very small watershed. So there are some factors there that are not easy to draw from the regional hydrology, but we did the best we could with monthly mean flow estimates, with high and low bounds."

Chuck: "If you had taken the 1800 mm to 2500 mm which you estimated for the site at El. 4500 feet and brought that down to sea level, by about 5% per 100 metres, where would you have ended up?"

Roger: "That would have brought you down to about 1415 mm which would be about 20% high compared to the 1200 mm that you found by trial to be necessary."

Yaroslav: "The people who did the power studies would have been conservative and used the bottom of the range for the runoff so we could use the bottom of the range, 1200 mm, for the precipitation."

Roger: "In this case it could have given you a pretty good answer."

Chuck: "That's a good way to put it. In this case you could have been lucky."

Yaroslav: "But I found it very awkward to be going by trial and error in a case where I had good information for a site and I couldn't directly input it to the program."

Now I had another problem which might have been because we were using Tasu weather data out on the outer coast which is a very maritime climate and we were trying to apply that data, not just for precipitation but also for temperature. Our site is in the coast mountains at a high elevation which is glaciated. This led to a problem, particularly for the year 1976, where the model produced several flood peaks which I had trouble believing. I got a peak here in January, a big one in February, another in March - 1976 was the worst year of the lot. There were several other years where that behaviour was more typical. Usually you don't have any major peaks in the winter period."

Roger: "Did you run it on Atlin?"

Yaroslav: "No. I tried, but the program bombed out on me and I decided not to spend time trying to find out what was going on. Instead I stayed with the one that I could work with conveniently."

Chuck: "Is Stewart the station that's on a long arm of the sea?"

Yaroslav: "Yes, that's the Portland canal."

Chuck: "There are very strong winds through that area and the climate varies from maritime to interior depending upon on how those winds break out. On any given day it may be cold and dry or warm and moist depending upon the winds."

Yaroslav: "That's right. It's an area with a high gradient, with maritime air on one side and interior air on the other."

Chuck: "Probably the methodology is in appropriate in an area like this where you have neither one nor the other type of established climate."

Yaroslav: "Well, over the year, I would think that things would tend to average out. On an annual basis, I would think that it's possible to come up with a reasonable type of trend.

Danard said that the reason for the discontinuity was the way in which he had prepared the grid. This area is where two pieces of his analysis overlap and the match here is not perfect. He never did a maritime analysis in northwestern B.C. anywhere east of the panhandle. His analysis assumed that the continental climate extended right to the U.S. border on the panhandle, and of course this is not really true. There is some maritime influence on the Canadian side. There is a strip of B.C. here which should be excluded completely from the grid."

Roger: "Really, if you didn't like the results you got using Tasu, you probably should have run it on Atlin weather data. It's unfortunate that the program crashed because it would have been interesting to compare the two sets of results."

Chuck: "Well this still bothers me a bit. One regime is responsible for the accumulation of the snow while the other might be responsible for retarding or accelerating the snowmelt. Thus, the seasonal distribution may become scrambled."

Yaroslav: "That's right. What I really needed was some temperatures from a place like Atlin and the precip from Tasu. But, again, there is no ability in the package to do that.

The next thing I did was to go into those parameters which we were not supposed to touch. I have used the UBC model before and in the theory and modelling procedures portion of the manual there is some discussion of those parameters. If you have a basic understanding of how the UBC model works you can go in there and adjust those parameters.

In addition to the problem with the peaks in the winter, I also had a problem with a steady high ground water level. This didn't seem appropriate for this site. I don't have a lot of recorded data to support that but the regional data seemed to point towards very low winter flows. So, I changed some of the parameters and I was successful in pulling the winter flows down to where they should be. Again, it was by eyeball and a general feeling as I didn't have a lot of data to work towards.

After I'd done all this work I put the simulated flows through POP using the configuration for the project as conceived by the engineers who designed it.

It's a small catchment with a fairly large lake in it perched up high with about 340 feet of head and 1400 feet of penstock length. The scheme was to put a dam in to raise the lake. When that storage was utilized additional storage could be drafted by pumping from the lake against a small head.

I did two simulations, one was based on 1100 mm of precipitation and the other was based on 1200 mm of precipitation. One resulted in flows slightly less than those used by the engineers, the other in flows slightly higher. The one that was slightly low actually ran the reservoir down to below its lowest limit in a few critical years. With the other the program was successful in producing the desired target output of 1.5 MW. The program was producing, typically, numbers such as 1591 KW, 1583KW, 1603 KW, as average output for the year. That extra 100 KW output might represent the generator and transformer efficiencies which were not accounted for by POP. Although my power output was slightly higher the results seemed to confirm the flows and power estimates that the design engineers were using. So that part of the model seemed to work well.

For this mining project the power studies had not yet been taken to the level of detail which would account for variation in loads throughout the year.

On the flood frequency analysis I had one run and I got a roughly similar flood frequency curve compared to that produced by the regional method. The flood frequency line was higher but sloping less than the regional study curve and they intersected at about the 100 year return period. In that one case which I plotted it seemed to be not too bad but I am a little leery of the theory that goes behind it. I would personally check every frequency curve with the regional analysis anyway."

Chuck: "I have more problems with regional flood frequency analysis in the mountains of B.C."

Dave: "On the PRECIP package it became evident to us all last week that there are some fundamental problems in interpreting what Danard meant by the precipitation values. There is therefore a need for recalibration of the watershed model with a correct understanding of the precipitation grid values.

One detail, on the computer which I used, a COMPAQ Deskpro, it did not give me the flashing data point in the centre of the grid. I could not even read that data point and the only way I could get that point was to deliberately miss where I was going and then read it from an adjacent point. I tried it with both the colour and monochrome settings. I haven't had any other problems with that particular computer.

Moving along to the streamflow simulation component, I looked at a catchment in northwestern B.C. This watershed is north of Stewart. I did a hydrology study for a proposed gold mine north of Telegraph Creek in a catchment called Bearskin Creek. I had great difficulty in deciding on the mean annual precipitation and the streamflow variability at the location. Subsequently we monitored the stream for a year. We found that my original estimate was very good on the low flows, but it was not very accurate on the high flows. In fact the mean annual runoff was much less than I had anticipated.

It was purely by chance that I was reasonably accurate on the low flows. It happens that a major source of the streamflow is from a lake which is founded on porous materials. The lake fills up in the summer time and drains out through this porous material, which acts like a regulating reservoir. This provides a sustained base flow through the winter. This is rather good for a downstream hydro site because it has some natural regulation. I thought that this would be a very good catchment to test out the BCSIM model.

I used the PRECIP program and went through the procedures exactly as outlined in the manual, with Atlin as the weather station and Cottonwood River for streamflow data. Because of the work I had done up there I knew that this watershed fell on that side of the catchment and climatic characteristics of the region.

The results were remarkably accurate. Absolutely astonishing. The results were spot on and followed the flow duration curve that I had plotted up for that one year of data.

I then ran the results through the POP program, with a correction for the efficiency of the generators, and came out with a reasonable calculation for the overall energy generated. So I thought that, well, this is fantastic - this is really something and now I'll try it somewhere else in the Province. So I took a look at a small catchment, Peterson Creek, south of Kamloops. It wasn't a hydro site but it was a small catchment on which I had done some work. This is on the plateau above Kamloops. The region was the Southern Interior, the atmospheric station was McCulloch, and the basic streamflow data was for Pearson Creek. In this case the BCSIM package gave me flows which were five times larger than the recorded flows. There is a water survey of Canada gauge on Peterson Creek.

I tried everything I could think of to improve the agreement. I played around with the deep zone groundwater parameter, in fact I set it to zero, to try and drag the base flow down, but after the first year it just climbed back up again.

So I began to think about this from a hydrological perspective and it is relatively simple to come up with explanations for why it works in Bearskin Creek in northwestern B.C. in that particular application, and why it didn't work on Peterson Creek.

In the north, the Cottonwood River has an unusually high sustained base flow. This is an 880 sq. km watershed. Whereas, if you take a small catchment in the same area, it won't have that high sustained base flow in the winter. This Cottonwood

River idea works for the Bearskin Creek catchment because of the artificial situation where a debris slide provides pondage which sustains the low flows."

John: "Although the Cottonwood River is a little different it does fall in the same general area, and what is the distribution of the mean monthly flows? In terms of the percentage runoff?"

Dave: "But a small catchment up near the Cottonwood River would have zero runoff during the winter."

Chuck: "We didn't have any small gauged watersheds up there to calibrate with, other than the Cottonwood River."

Dave: "Yes, I am just going through all of the thought processes that I went through in trying to explain this situation. So, now going back down to Peterson Creek in the southern interior, I know that the climate would be very different from McCulloch, in terms of evapotranspiration, catchment characteristics for Peterson Creek would be different from Pearson Creek in terms of the interception on the catchment, the amount of snow cover that you would get, the amount of blowing snow, and evaporation from the snow pack during the winter. And in fact there is a very low runoff relative to the precipitation in Peterson Creek. So the conclusion that I came to was that if you are trying to model a catchment which happens to have the same climate, or a very similar climate, to the climate of the reference atmospheric environment station, **plus** it has very similar catchment characteristics to the catchment which was used for calibration, **then**, you get very good results.

I also did a few spot checks with the precipitation grid and it was interesting listening to Yaroslov's comments. There is a catchment down here called Forest-Kerr. It has an annual runoff of about 3,300 mm, which is very, very high, whereas the precipitation grid indicates that the mean annual precipitation on the Forest-Kerr watershed is about 1200 mm. This is only about one third of the mean annual runoff. The 1200 mm included multiplying the precipitation grid values by the factor of two as indicated in the manual for this region.

So I concluded that you must have two things in place. You must have, a climate which is the same, or similar, to the AES station, plus you must have similar catchment characteristics. This leads to a fundamental problem with the IMP package. We have six regions in which climatic and hydrologic homogeneity are implicitly assumed. This situation simply does not exist - the regions are too large to represent climatically homogeneous and hydrologically homogeneous regions."

Chuck: "We had a real problem with this at the outset in the development of the package. You may remember this Neill. We really didn't believe in hydrologic regions. That concept was intended to beg the question and everybody was in agreement with this problem."

John: "What you need is the ability to put in data for more AES and Water Survey of Canada stations."

Chuck: "Well you can do that. This is what you are supposed to do when you get working with the package on a routine basis. You add your own data to the database. Then you would recalibrate the watershed model and run with that."

Roger: "In theory, if you had enough time, you could do as much recalibration as you felt necessary."

Dave: "Surely there is a concept of a hydrologic region if you get small enough areas."

Roger: "You might find some homogeneity if you analyze enough watersheds, even if they are in different areas."

Dave: "But whether or not you believe in hydrologic regions it's implicit in this package that there are such regions."

Chuck: "That's right and that's been a problem."

Dave: "You can't get away from that."

Chuck: "This goes back to a comment made earlier. I have a serious problem with regional hydrology analysis which does not directly incorporate climatological variability with the same level of emphasis placed on streamflow data. In our view, you must be very site specific. This package is a step in parallel with the regional hydrology analysis. I don't know how to break out of this box, it is not the right thing to do, really. You people have a great deal of experience and know how to deal with this. This is not a field for a novice."

Dave: "A considerable benefit from this package is in making the UBC Watershed Model available for the first time to us poor guys working in the sweatshops of Richmond and Burnaby and wherever. That's a significant benefit of this work. It's not quite as useful a tool as it might be if it was made more flexible so that you could get at it better within the package.

One suggestion would be to completely delete missing data from the records in the database. It is very irritating to run this package when there is missing data. At the very least there should be a summary for each of the stations which tells you which years have missing data and if it's significant or not. We could live with a few days of missing data here and there but when there's a couple of months completely missing its very annoying to find that out after you've gone through all of the simulations."

Chuck: "I was wondering if there wasn't some way we could use the Water Survey of Canada data to fill in the missing weather records so that when you use them you get the right answers."

Dave: "A better method is needed. Either delete the missing data or find some way to fill it in."

John: "I started my run for the period after the missing data."

Tung: "The simplest way is to continue with your simulation and ignore the year with the missing data. When I used the time series for Carnation Creek I knew that there were three months of missing data in 1979."

Roger: "If it's only temperature it's not that crucial if it uses the previous day's temperature for the whole month. I have made a list of what's missing and which periods are wet or dry. These are some of the best records that we can get. It's unlikely that we will do much better."

Chuck: "It's unlikely we would do better with real data, but we might do some kind of analysis to fill it in."

Roger: "I think we would be better to leave it out and just run for a five year period if it's necessary."

John: "Five years is a little short to get a good meaningful average."

Dave: "You might be able to fill it in by correlation with another AES station."

Chuck: "It should be possible to fill in the missing data by referring to the synoptic charts and Water Survey of Canada streamflow records. If the streamflow record shows a flood peak on a certain day it's a pretty good guess that it rained that day. At least it rained that day on the watershed being used as the indicator basin. There aren't that many months of missing record. This would be a labour intensive job but it would only have to be done once. At least this would work for the base AES station."

Yaroslav: "I think we should get away from the base station concept completely and open the whole thing up so that we use all of the AES stations. We should allow people to access the parameters in the UBC watershed model in some conveniently understandable fashion. The watershed model has been somewhat limited in its calibration because of the lack of AES data."

Chuck: "I don't understand what is meant by calibration which is dependent upon the climatological data."

Dave: "The calibration uses the AES data as a basic input."

Chuck: "Yes, but you can't eliminate or create a flood peak in the output of the watershed model by changing the watershed parameters. The only way that you can do that is by changing the AES record. In this type of simulation analysis the model is calibrated to represent the routing and storage characteristics of the watershed. The input data comes from the climatological station. If you take the calibrated model and put a different weather system on it, if the model is calibrated properly, it should give you the correct output."

Yaroslav: "But in the watershed model we are taking perfect data, transposing it from far away, and expecting to get answers which are meaningful. To do this you must apply fudge factors, such as the lapse rates, and you might find in one area that regional characteristics are different from another. For example the variation of precipitation with elevation may not be the same on the Coast as it is in the Rocky Mountains. Thus, the results may depend on both the AES station which is used in the calibration and the catchment factors."

Chuck: "Consider the lapse rate for example. I wouldn't be surprised if the lapse rates are quite different for the interior region than they are for the Coast. The lapse rate concept is an approximation to the things which really happen in the mountains, including inversions and whatever other factors might account for differences in the climate of those two regions. Those are basic very gross atmospheric calibration parameters. They would be expected to prevail along the entire coast, or through the central interior, or through an entire region. If you move around within those regions those factors should not change. What should change could be something like this ground water factor that has caused a bit of confusion. That would be very site specific.

Basically, the calibration parameters which a user should be looking at, would be those which relate to the watershed routing and storage behaviour. He would not be calibrating the atmospheric aspects of the simulation model."

Yaroslav: "Right, but to make the thing work, if a station is changed, it might be necessary to change the calibration. For instance, in my case here where I was using Tasu and getting flood peaks in the winter where they probably would not have occurred, the suggestion was made that I should use Atlin to provide better winter results. So if I had used Atlin weather maybe I would have had reasonable winter flows, but the precipitation would have been much less because its so much drier there than it is near the Coast. I would have had to do a different, so called calibration to get reasonable answers."

Chuck: "It would have been ideal if the model would allow you to use the precipitation data from Tasu and the temperature data from Atlin, perhaps even at different times of year in the same simulation. This would allow the model to accumulate water from the Coastal climate and melt snow using interior data. But it should not be necessary to change any of the calibration parameters in order to do this."

Yaroslav: "But there still would be station specific characteristics to account for in calibrating the model. Maybe your definition of calibration is different from mine - I mean twiddling all the little knobs in the program to get the right outputs from this data."

Chuck: "I agree with your concern. The intention of the package was to encourage the user to base his analysis on all of the available data, not just the six sets of data provided with the package. It was not intended that they would be exclusive of all other information. If you have data within your watershed you should use it. It was also intended that most users would not change the calibration parameters of the watershed simulation model. That is, unless you wanted to undertake a special study for some special purpose.

The parameters that are in the model now were based on more than just the data that was supplied with the package. Within each region there were several stations which were used in the calibration. It was a flip of a coin almost in deciding which data stations to include in the package."

Dave: "I think we have reached agreement here that the package should be used only by qualified Hydrologist who have the experience to interpret the results. Furthermore, to make it useful for a qualified hydrologist it needs some additional flexibility."

Chuck: "Yes. It is a bit of a dog's breakfast the way it stands now."

Dave: "Now, changing to another topic for a moment. I didn't have time to go into the flood frequency package, FFA, in any detail. My feelings are that most hydrologists prefer a regional approach. My conclusion about this component, again, is that it would be useful to someone who is qualified as a hydrologist. It provides one more tool at his disposal.

I have a problem with the potential for applying the POP programs to small hydro projects. These were developed for B.C. Hydro for application to large reservoirs and generally speaking we don't have the luxury of having a reservoir with a small hydro project. A more serious criticism is in the optimization component which uses a single value for energy which may be fine for B.C. Hydro but in small hydro the economics are much more complicated. There are often three components to the energy equation. There is the cost of diesel makeup, the value of the energy directly to the developer, and the value of the surplus energy which he can sell. These three things greatly complicate the economic picture. An exception would be in some place like California where there is a fixed price which the regional utility offers for purchasing the output from a small hydro plant. For most applications in B.C., for mines and small communities, the picture is more complicated because the plant is not just selling into the grid. We are invariably involved at least in diesel makeup. Very few small hydro sites can provide 100% of the requirements all of the time.

The default turbine efficiencies in POP should really be default overall efficiencies.

GAP is a very important component of the package as it is the only tool for obtaining data summaries. Unfortunately, as presently configured it has quite a few shortcomings. It should be able to generate monthly, yearly and total data summaries. That is the first thing you should get out - a good data summary in tabular or graphical form. It should include minimum and maximum values by month, by year, or however you want it.

It should also be able to generate flow duration curves for the entire period of record, not just year by year. If we are still going to have missing records we should be able to delete those from the analysis.

That concludes my run through the programs and I have three major conclusions:

1. The package, primarily because it is extremely ambitious, does not achieve its primary objectives. It doesn't provide accurate prediction of flows in ungauged watersheds. As it is presently set up, as supplied to us, it doesn't do that.

It can do that in specific instances, but it doesn't do it in general. It is not sufficiently accurate for a first cut hydro analysis.

2. It is of value to qualified engineering hydrologist, but it should not be used by the general public or by engineers without a sufficient hydrology background.

3. To make it useful for the engineering hydrology community the package needs more work.

Adrian: The big points, which are the easiest to lose sight of because they are the hardest to get a grip on, are whether or not the approaches are correct. My comments repeat some of the ideas which have already been said, and perhaps this is useful because it does show some measure of consensus.

I am more comfortable approaching a small hydro feasibility study from a streamflow base rather than from a precipitation base. Streamflow is basically what it is all about. If you have to go to precipitation you are one step further removed and this introduces quite a large degree of uncertainty. Personally, I will do anything I can to use streamflow and forget about precipitation if at all possible. That means of course going to the regional analysis. It is usually possible to come up with some kind of estimate for streamflow in your ungauged catchment from some other gauged catchment however remote or dubious it is. That would be my first approach, even now, having been through the IMP package. That's my fundamental reaction to this package. I am basically uncomfortable with the approach of using precipitation.

However, let's accept that we are going to use precipitation and have a look at how that's worked into the general scheme of things. Again, I question whether we can really divide the Province up into six regions. These regions are very large and there is tremendous variations within each. That makes me feel insecure, to put it mildly, using this regional precipitation approach.

We then get into the complex web of the precipitation grid. Quite honestly, I still don't understand what these precipitation values represent. My most recent concept is that they represent precipitation at an elevation which is somehow representative at an AES station, or a series of AES stations on a plane of AES station elevations which undulates over the Province. These precipitation values have somehow to be adjusted to the catchment of concern, but that's the extent of my understanding."

Chuck: "It's actually not undulating. It's a series of step functions."

John: "The manual says that they reflect the influence of topography."

Adrian: "That's right. These grid points are supposed to reflect the elevation effects and in fact they don't. Other than the elevations of the base stations which were used in creating them.

Another global issue is that we should not delude ourselves into believing that this is a package for the layman. I think we should forget about the use of this package by anyone except engineers or people who are hydrologist.

For a test application of the package I chose a site in the southeast region of the Province on the Kicking Horse River. This catchment is on the B.C.-Alberta border and the hydro site was specifically aimed at replacing diesel generation in the town of Field. The study was done six or seven years ago.

I applied the IMP package although the Kicking Horse River has the distinct disadvantage of having Water Survey of Canada gauges on it. Horror of horrors, there's even a gauge right at the site. Admittedly there are only six years of record and these data are from 1918 or so. There must have been some construction activity after the railway went through and that's probably why the gauge is there. The more recent records are further downstream at Golden. So, this gives us a wonderful opportunity to have a look at the output from BCSIM.

Now, it's simple enough to use PRECIP and follow the recipe given in the manual. I went through the motions of interpolating from the grid and applying the fudge factors. I did not have precipitation data for the catchment so that I could make a comparison, so I just blindly went ahead and used the precipitation procedure.

I then went to the flood frequency analysis specifically to compare with the frequency analysis which we had done using the Water Survey of Canada gauges. The results were something like 50% higher than those given by the standard frequency analysis based on the Water Survey gauges. Now there was a bit of correlation involved because we had to work from the downstream gauges to correlate with the gauge at the site. The drainage area of the watershed was 125 sq km and its a high watershed all above 1500 metres."

Chuck: "One problem may be that FFA calculates the area producing runoff as a fraction of the total catchment area using some internal heuristic routines. The assumption in there is a bias towards very small watersheds of perhaps ten sq km. That ratio as it appears on the screen may be close to 1.0 whereas on larger watersheds it really should drop. On a very large watershed it should drop to about .4 but that's not built into this package."

John: "Another point is that FFA asks for the rainfall, not the precipitation. Therefore it is a rainfall flood which is is analyzing, not the floods produced by snowmelt."

Chuck: "That's correct. The snowmelt part that's in there could be used if you had a snowmelt simulated record which could be analyzed like rainfall. Since you don't normally have that you would input zeros for the snowmelt parameters."

Adrian: "I then went into the BCMAN component and did a careful job of feeding in the sub-basin characteristics. This is a basin which has significant glaciated portions. The upper elevation band had 30% of the area in glaciers and the next one down had 10%. The tree cover factors were reasonably accurate, at least as far as I could tell from a 1:50,000 scale map. I then ran BCSIM and developed a comparison with the mean flows generated from the Water Survey gauges. It appeared to me that, in this case, the model was low by something like 50% or 60%. Here I am talking about the series of annual mean discharges. This is a serious enough error to give me some doubts about the validity of the analysis."

John: "I have a question about the glaciated areas. Are these input as a percentage or as an area?"

Adrian: "I assumed that it was a fraction."

Yaroslav: "I assumed that it was a straight area. That appears to be the only one like that. Impermeable areas of the bands appear to be fractions and the tree cover is given as a fraction."

Chuck: "The problem that I have is whether the glacier portion works at all since glacier melt may be primarily a radiation effect and a different routine should be used to develop the coefficients for the degree day approach."

Roger: "Adrian, did you compare the precipitation values given by the PRECIP program with any of the precipitation values for AES stations in the area?"

Adrian: "No, I didn't."

Roger: "I am tending towards the theory that if you have measured data you should use it instead of values given by the package. If you don't have anything then you could use the precipitation grid, but I have run across so many discontinuities in areas of high precipitation gradients that I like to go looking for AES data to see if the PRECIP output is up or down by any consistent factor."

Adrian: "I didn't make that comparison."

Dave: "How does the watershed model account for different slopes? My experience is that in the Rocky Mountains slopes are very steep and I would expect there would be very high runoff. Pearson Creek which is the calibration catchment for this area has relatively moderate slopes."

Roger: "I think the calibration included Illecaewit and one other up in that area of the Columbia River."

Tung: "The Theory manual indicates permeable fraction of area, but for glaciated areas the area is in square km."

Adrian: "So that would explain why the computed flows would be less than the gauged flows, although not by 50% or 60%."

Chuck: "Well that should increase the runoff by more than 30% because most of the runoff is coming from the higher elevations."

Dave: "Not from a glacier."

John: "But all the rainfall runs off from up there."

Tung: "Was that one band or two bands?"

Chuck: "We will have to check to see if it using the fictitious small glaciated area which Adrian put in or if it uses area from the hyposometric curve."

Yaroslav: "I am pretty sure that you take the total area of the band and then you come back later and put in just that portion which is glaciated. The glaciated area therefore always must be less than the total area. Having used the UBC watershed model before I am almost certain that it would be a component of the total area even though its not put in as a fraction. I don't think it would make the band area smaller if you put in an incorrect small number for the glaciated area".

Adrian: "Well, I went ahead and used POP1 to set up the data and ran the simulation with POP2. I ran a 7 year continuous simulation. The first year and the second year looked sensible, but the results for all of the other years were the same as those for the second year. There is probably a simple explanation for this, but I didn't have the time to come up with it."

Patrick: "Did you check to see if the flows were always greater than the maximum turbine capacity?"

Adrian: "The mean flow was certainly always much larger than the maximum turbine flow."

Chuck: "Neill and I had the same experience with a problem we were running. The problem wasn't from POP, it was from BCSIM, and Tung identified the problem. When you run BCSIM it asks if you want the detailed output for calibration. If you say yes then this error occurs."

Adrian: "Well, I didn't say yes. I got constant output from POP2."

Patrick: "You should check your minimum flows to see if they are always higher than the maximum turbine flow. In this case your turbine will always be running at capacity.

Adrian: "That's one possibility that might explain it. That's as far as I could take the actual comparison because in looking at feasibility at this site, we actually had a reasonable handle on the load and matched the installed capacity to the load. It wasn't a situation where we put in a larger installed capacity and sell the power to someone else. We opted for 425 a KW installation while the POP3 optimization suggested a much larger installed capacity.

POP3 recommended some 700 KW and I ran into problems in not completely understanding what it was giving me. Was it recommending an installed capacity or giving me a mean power, or what? The number that it came up with was 710 KW, which I think is the recommended installed capacity. That corresponds to something which would be available less than 75% of the time. This obviously doesn't correspond to what we selected because we want to meet the existing load."

Roger: "Now you had some default flows where your values were steady and those might have been put through POP3. What sort of output were you getting on your steady results?"

Adrian: "For the whole period it was giving me an average power of 330 KW which is not far from the 225 or whatever that we selected. We would probably have ended up with a higher installed capacity if we had been optimizing to extract everything we could out of the site."

Roger: "That would agree if your BCSIM results had given you high flow and your installed turbine flow was lower than that maximum. In that case the optimization would be concentrating on those last five years of steady flows and disregarding the first two years of your BCSIM streamflows. So you may have ended up with a value that was biased by the last five years."

Chuck: "I may have missed something here. The economic calculations in POP3 indicate that it would be worthwhile to install 700 KW even though the last 400 KW would only be operated 25% of the time. Presumably, using the costs and values that you selected this would generate enough revenue to justify the cost of constructing that large capacity."

Adrian: "Well in that case I understand what this is, but I'm not in a position to make a strict comparison because the earlier studies didn't go to that stage. So the studies may well be consistent for all I know."

Tung: "First of all the range of installed capacities used in POP3 should be close to the value used in the POP simulation. For example, if you use .2 cms in the simulation with POP2 you should use .1 to .3 as the range in the analysis of POP3. The key assumption in POP3 is that the static head and turbine efficiencies are constant within the range. If you did analyze something around 300 KW and the optimization suggested 700 KW as optimal, you should go back and do the simulation again for an installed capacity closer to the optimum. Otherwise the derivatives will not be realistic. The right answer might be closer to 500 KW.

The range that you investigated was from .5 to .8 cms, whereas the actual simulation was carried out with an installed capacity of .2 cms. So the analysis covers a range which is far removed from the actual simulation. The assumptions in POP3 may not be valid in this case."

The maximum value in the power column is not the optimum. The optimum occurs where the marginal costs equals the marginal benefits, their ratio is 1.0.

Roger: "The program should provide some guidance so that a value is chosen close to the value used in the simulation. "

John: "You should bracket the simulation value as a first step."

Roger: "The program could be modified to comment on the screen that the optimum occurs where the marginal value divided by the marginal cost is equal to 1."

Adrian: "In conclusion, my main hesitation relates to the streamflow simulation. I think that the POP programs are potentially very useful and if further money is to be spent on this package I would like to see those POP programs modified to be more applicable to small hydro applications. I would rather not put more money into the BCSIM side of things. It has been described as "ambitious", but perhaps "impossible" would be a better word.

If somebody does want to put more time and money into the watershed model that person should be Tony Pipes, possibly with the help of some cheap labour like a graduate student. This is an open-ended mammoth project and it may not be a sensible thing to do. Even if you manage to calibrate the thing to work perfectly with the selected stream records, I am still not convinced that you could sell it to practicing engineers as a tool that could be applied willy-nilly. Maybe I'm just a died-in-the-wool skeptic, but I like to get my hands on some streamflow records and know what I am doing. So I come back to this wretched regional approach every time.

However, I think that the POP programs are potentially very nice little programs which could help tremendously in assessments of this kind. I think it would be well worth developing those to make them good and tight.

Yaroslav: "If POP2 is to be enhanced it will still need daily streamflow records of some type or other. Regional studies are not going to give you daily streamflow values whereas BCSIM will. You may not have a stream gauge right on your site and the nearest one may be some distance away and maybe not very representative. It may be a very large watershed with large base flows. What do you do in a case like that?"

Adrian: "There will always be problems like that. I think POP2 has to be modified to be less demanding when it comes to daily flows. I think that many feasibility studies have been done with mean monthly flows. I think that a daily time series of flows is a luxury and may not be required for this level of study."

John: "So what you need then is the ability to take output from BCSIM and generate monthly mean flow."
Adrian: "Yes."

Dave: "Perhaps POP could be modified so that you could input flow duration curves how ever you derive them, from monthly values or daily values, that's a detail. Then POP could operate from there. Use the flow duration curves instead of a time series."

Yaroslav: "There are definite benefits to the daily time series. They point out difficulties that you might have in reservoir operations that might not come to light using monthly values."

Adrian: "But there are no reservoirs in small hydro studies."

Roger: "There is another point. Could you not use regional values from the Water Survey of Canada data modified so that you could use something off your Water Survey of Canada data base using a representative stream. You could down-size that streamflow record and use it for input to your POP simulations. There is a lot of value in the POP simulations and a lot of information. Why throw it away? The package gives you the option of using the results from BCSIM or working with something that has actually been measured and modifying it appropriately. This way you could be sure to get the correct mean annual runoff and still see the details from the daily analysis."

Chuck: "POP has a hook in the code now that will allow you to modify a streamflow record by a constant factor, which might be based, for example, on the ratio of drainage areas. That hook is currently dormant but it could be re-activated. You can read any Water Survey of Canada data file that you prefer and the program will scale it, or down-size it, as Roger would say. This is almost what you do with a regional analysis.

Using the daily series you can get the energy output correctly. With an average monthly value the correct efficiency is not used. You need a weighted average efficiency which you don't know unless you have a daily time series. There is also some potential for discussion about hourly variations because a turbine may be running at capacity for only a portion of the day.

I don't see any major problem in addressing Adrian's needs by simply reactivating that hook that's in POP. The program simply asks if you want to scale the flows and you can reply by inputting that factor. Instead of choosing a BCSIM output file you can choose a Water Survey of Canada file."

Adrian: "I think that would be a very realistic approach."

Chuck: "At present you don't have to choose BCM output files. You can run Water Survey of Canada files through the package. It is smart enough to recognize any differences in format."

Dave: "There is no question that that would be a very, very useful tool. Now you are talking about something really useful."
Chuck: "This is the same approach used in GAP. It is designed to work with any data series. The data doesn't have to be generated by this package."

Dave: "What we want is maximum flexibility so that we can do what we want with this package."

Adrian: "If the GAP program could be polished up a bit it would be a very useful tool. We need the flow duration curve for the entire period of record, not just for one year."

Tung: "We realized that problem when we wrote the package, but it was impossible to implement at that time because of the computer and compiler limitations."

Adrian: "There are some other minor points. Some of the tabular screens in GAP were missing units. Also, it would be nice to have a grid on the plots."

Yaroslav: "It is tedious to make the screen dumps to the printer. There is a form feed after every graph and it is time consuming. Flexibility to look at several years on the screen at the same time and to pick and choose the variables to be plotted on the same screen would be useful."

Chuck: "There are commercial packages which provide better control over the print screen operation, including the ability to put several graphs on the same page."

Patrick: "My general comments about IMP include that it's not suitable for the non-technical person. It is however suitable for the engineer, especially if he has some knowledge of hydrology as well.

As far as the precipitation model is concerned we need to clear up that equation 2.1 to determine whether or not Tony Pipes knew that the grid precipitation was at an elevation of the interpolated AES stations.

As far as the streamflow model is concerned, for the regional approach here, I would have gone for a lumped black box model like the kinematic wave model. The other alternative is to use the simulation type model like the one used here.

I would like to see the calibration capability of the UBC watershed model added to BCSIM. That would include a statistical package which would be in-built. That's what you use with the UBC Model on the mainframe and that's what you need to calibrate.

I don't think there's any point in using other AES data unless you've got the statistical package. So, for the normal use of BCSIM, we would eliminate a lot of the watershed parameters that you are not supposed to change anyway and provide a calibration option which would include all those parameters as well as the statistical package. This would work on a daily basis as well as on a monthly basis in terms of volumes so that you could see what is happening.

A more detailed user's guide would also be useful.

This has all been done. The user's manual was prepared for B.C. Hydro some years ago."

Chuck: "The present user's manual was abstracted from that B.C. Hydro manual and other publications about the UBC Watershed model. Getting additional documentation about this model was like getting blood out of a stone.

If anyone would care to take that B.C. Hydro user's manual and re-write it we would be very grateful."

Roger: "But what about this calibration version of IMP? How do other people feel about that?"

Dave: "Yes. I made the point earlier that this is the first time that the UBC Watershed model has been sort of available but in such a form that you really can't get hold of it. It's kind of frustrating."

Roger: So maybe there should be two levels. The level at which Patrick suggested, a visual level, in which you can change perhaps only three parameters on the screen, and the second level where you type the parameter file in an editor or something. At this second level there would be about four pages of parameters. Can this be done within the present program? At this second level which parameters would you modify? How would you go about doing the calibration?"

Chuck: "There is a very clear cut procedure for calibration. There is an existing calibration version of the program which we wrote to help Tony with the calibration. That program includes graphical displays of both the Water Survey of Canada records and the simulated results and does some various and sundry comparisons of numbers. It could be modified so that you would get the statistics dropped out the bottom after a run."
Patrick: "And the user's manual should give you the range of parameters and what will happen if you change them."

Roger: "What I'm wondering is whether this gets built in as a supplement or as a separate program."

Chuck: "It should probably be a totally separate program that would be popped into the package into another slot, as a separate module selected from the main menu."

Patrick: "This work would be extremely time consuming if you started from scratch, but the fact that you have the thing calibrated for the six different regions should put you in the right ball park. A lot of work has been put into it, not just for one basin within each region, and I think that will be quite useful."

Roger: "I think that we are going almost an order of magnitude beyond where this project started with the farmer who could make some kind of analysis without having to put in 15 parameters. If we can get that order of magnitude and attract a different level of user that can usefully apply it I think it's realistic. If we can manipulate a few things here without a major budget requirement, it would give you guys here a new level of approach and we might still maintain our main objective by cutting out this second level of analysis. We may want to address the ranchers and farmers in a different way."

Adrian: "Well, if you are going to go in this direction then the package becomes much more general, it's not just applicable to small hydro, but it's applicable to flood control, etc."

John: "Perhaps the program could come up with some warnings about the qualifications that might be necessary to run this program."

Roger: "I think it's a good point that's been made here about the usefulness of expanding the package to include the calibration option. This will make it available to a larger audience."

Patrick: "I think we can go further and say that it's generally been agreed here that BCSIM as it is should not be released. There is too much variability in the answers which it produces. But if you had a calibration option it would make the thing more usable and we might salvage what has been done.

The watershed which I selected was the Goat River which is in the East Kootenays near Creston. I have not actually done power studies on the Goat River but there is an arch dam there with an existing power plant which has not been working for a good many years. Tony Pipes has just done a PMF for it.

So, according to IMP I am supposed to use McCulloch and there is a Water Survey of Canada gauge.

On my first shot I got one-third of the measured flows. Then I went back and looked at some nearby stations and realized what was happening. Now the Goat basin has a mid-elevation of about 1500 m. and the McCulloch station is about 1250 m. This seemed quite close. The nearest AES station is Creston which is at about 635 m. The mean precipitation there is about 530 mm and the mean at McCulloch is about 680 mm. Somewhat comparable, but with the elevation difference it means that McCulloch is coming in just below mid-elevation and it's just not being increased enough in the model. The model wasn't getting enough precipitation in there.

When I used BCSIM I adjusted the regional factor by the ratio of the mean runoff which the model had given to the mean measured runoff. Of course, that gave much too high a flow. Then I began doing some trial and error work. I ended up with a rainfall transposition factor of 0.92."

Roger: "So your precip was about 1300 mm, was it?"

Patrick: "No, the mean precip was about 680 mm. The first time I changed the 1.15 regional adjustment factor in the ratio of the runoff. I had a runoff of 10 cms and it should have been 25 cms so I boosted the factor to 2.9 and of course that was too much. Finally I got back to about twice the value given by the precip grid.

I also changed the deep zone groundwater parameter and a couple of the others but of course that didn't do anything.

I did not use FFA to estimate the flood frequency curve because I had increased the precipitation to such a large extent. I didn't really think that the flood frequency analysis would provide reasonable results."

Adrian: "The determination of peak flows is not really a critical thing in the assessment of small hydro. It is something you need for design but its unlikely to affect feasibility."

Patrick: "So then I went into POP. Here I ran into the same problem that Adrian had. The first year I had some variation in energy and the second year I just got this straight line, and the third year, the same, and so on. I thought I'd made a mistake so I went back and re-plotted the flows with GAP. I found that the flows were always just larger than the maximum turbine flow capacity, except in the one year. So I was getting a constant energy every year.

I checked these flows and they were all about twice, in the winter time, what the recorded flows were. Again, this is probably because I have distorted the whole thing by putting in too much precipitation. I could have gone back and played around with some of the components in the model, but without any calibration facility this would have been very difficult.

So the mean output from the model was about 1300 KW whereas the installed capacity now is about 1000 to 1200 KW. There are energy output records for a good many years, but I didn't manage to get a hold of them.

So the answer was in the ball park but I didn't go any further because I reckoned that I had distorted the thing by putting too much precipitation into it. I put the extra rain in to get the mean flows right but that distorted the seasonal distribution."

Roger: "Did you modify some of the time constants?"

Patrick: "Yes. These are the factors which affect the first two runoff components. They didn't change things. They may have made a change on a daily basis but on an annual or seasonal basis they didn't make much change."

Roger: "I was wondering if the deep zone parameter might have had an effect on the low flows."

Patrick: "Yes. That's one that I could have adjusted. It's an 1100 square km watershed.

I went on to POP3 and obtained an optimum power output of 6 MW. West Kootenay Power and Light had done a preliminary rehabilitation study for this project......."

Roger: "Your power simulation was at 1300 KW and that's a long way from 6000 KW. There may be a glitch in there. If you go beyond a factor of 2 or 4 or something you may have a problem with the optimization."

Chuck: "It depends upon where you are. If he is already out there to the right on the firm power curve the slope may be relatively constant over quite a wide range of installed capacity. You should really plot the whole curve or look at the derivatives on the screen. You can see it in the output. It prints the derivatives on the screen and you can see the rate of change."

Patrick: "Well, as I was saying, West Kootenay was looking at 4.4 MW up to 11 MW.

Well, that's as far as I went. Again, it showed that McCulloch is not good for that location."

Roger: "Well, the calibration was for Pearson Creek which is pretty small compared to 1100 square km. That's pretty far to try and push the calibration. It must be about two orders of magnitude.

The package was intended to be used for less than 1/2 a Megawatt. On Carnation Creek we are talking about 10 sq km and at Pearson it's maybe a factor of 10 larger."

Chuck: "For 1/2 a megawatt with 200 or 300 feet of head we are talking about very small watersheds. We ended up with Pearson and some of these other larger watersheds because there were not enough small watersheds that had continuous records of gauging."

Roger: "Pearson is one of the smaller ones."

Chuck: Yes, but in the North for example we use the Cottonwood which is some 800 square kms in area because there wasn't anything else that was suitable. It leads you to think that the model can be used on larger watersheds but it shouldn't be used for them because there are implicit assumptions all the way through the work and the parameters have been picked on the assumption that the catchments will be very small."

Roger: "This goes back to the calibration question. If they were all calibrated it would be reasonable approach."

Chuck: "The model was not calibrated for the Cottonwood River. The parameters that are in there are intended to be used with watershed areas in the order of Carnation Creek. The Cottonwood data is in there simply because its the smallest watershed which had enough data to be worth putting into the files. For example, if you look at the time constants for the fast runoff component it will provide a clue."

Roger: "It goes back to the calibration issue. These guys could have come up with better answers if they had access to the calibration version."

Chuck: "If you guys had the Water Survey of Canada records in front of you on the screen as well as your simulated output and a list of parameters along the top like a Lotus menu you could have popped up screens and changed parameters until you got what you wanted."

Yaroslav: "Well I did some calibration on this study here and even though there's a limited number of parameters that are accessible I could change the winter base flows substantially. I got them down to 1/4 of what they were initially."

Chuck: "The base flow factor for the Cottonwood River should be one that is intended to be used on a small watershed."

John: "But it's a large value for the Cottonwood, it's 2.9 cubic metres per second or something like that. The manual says to ratio that in proportion to the drainage areas."

Roger: "We're just pushing the model beyond it's calibration. I think this confirms the idea that we do need that second level as well as having that first level with even fewer parameters than it has now."

Chuck: "The base flow parameter is supposed to be scaled in proportion to drainage area whereas there are others which are not intended to be changed in that way as they were developed for smaller watersheds."

John: "Well then that should be in the program when the screen comes up."

Patrick: "This package is intended for small hydro but is this just in the BCSIM module or is it in the entire package?"

Chuck: "It's particularly important in the flood frequency routines which contain default values which implicitly assume that the watershed is very small. But there were decisions to make in BCSIM to get around problems. The decisions were always biased towards very small watersheds.

For calibration there were other watersheds with data but the records were rather short."

Yaroslav: "We have been talking about limiting the application by the number of KW but this is 1.5 MW with only 9 sq km. There is a tremendous head. It should be limited by streamflow. I lean towards the idea of making the UBC Watershed model available, not just for small hydro. There are numerous other applications where it would be useful. This is the first PC version to get out into a forum but there are a lot of other needs. If a more polished stand-alone model for the watershed simulation could be made available, a future package such as IMP could just tap into it. Rather than changing the UBC model specifically for small hydro it would be possible to plug in a new module."

Chuck: "That's one distinct advantage to leaving the existing package as a series of separate programs. Right now they can be run separately but also any one of them can be changed without affecting the whole thing."

Harry: "Let me sum up. One of the achievements has been that the UBC Watershed model has been made generally available in a form that was not available before.

I have also heard that POP is probably a reasonably good package to use but it might be more useful with an extensive Water Survey of Canada data base. This would allow you to simply base the power analysis on streamflow records."

John: "I think you should be able to directly input the maximum generation desired. Controlling POP with flow releases which are averages for the month does not seem to be reasonable for a stand-alone hydro plant."

Roger: "Well I think that there ought to be some information for the user about how the run the plant. A daily load profile would appear to be essential. You can input this indirectly into POP but you are going to have to interpolate between the peaks and the minimums and come up with a reasonable estimate of the average."

John: "But at the present time the best that you can put in is the average flow for the month. You can't put in the maximum or it will drain the reservoir."

Chuck: "This points out the difference between using reservoir rule curves to control the releases and using installed capacities throughout the year to get the same type of control. Because the program only allows control changes monthly, you get these plateaus throughout the output.

If you put a lower limit on the reservoir elevation each month the output may not drop to zero quite so frequently.

People who don't use optimization think in terms of reservoir rules and POP uses a conventional approach to these. POP allows you to input the maximum and minimum reservoir level rule curves in monthly steps. POP will use all of the water in the reservoir, within the capabilities of the installed capacity, down to the level of the minimum monthly rule curve. At that point it will stop generating until new water arrives or it moves on into the next month where the minimum level is lower. This is a very poor way to simulate operation. Really, you should be optimizing but we don't have that capability in the present version of POP.

The only reason power studies are done like this is because this is the way they have always been done by hand. People have automated the hand calculations by writing computer programs. The proper way to do a power study is to use an optimization procedure to figure out how to run reservoirs properly. In that case you wouldn't need the rule curves at all."

John: "There's one routine in there in the manual which is your monthly energy requirement but it doesn't show up on the screen. I thought that would be a good one to have in the package because I know how much energy I would like to produce every month."

Chuck: "Well POP has that capability in it but it's been canceled out for the purposes of the IMP package."

Dave: "In addition to the diurnal variation in a stand-alone small hydro application you have the seasonal variation in energy. POP doesn't allow you to put that in. The only way you can do that is by changing the maximum turbine flows."

Roger: "You have to do that and run it once to see where the holes are and then go back and fill them in."

Chuck: "For the Strathcona case study you used here in the first two days of the workshop, we went back to the office and used GAP to calculate monthly average flows. We then put them into a linear programming model and determined the optimum operating procedure. These results were then plugged back into POP to do the power study which included the daily fluctuations."

Dave: "But to do that you had to go back and use a completely different computer program."

Chuck: "That's right. I would like to see a monthly optimization routine included in the ultimate package. This would be POP5, or whatever. It would take the monthly flow values and return to you the best operating regime which could be then plugged into the simulation studies."

Yaroslav: "But if you do that you're using mean values. The purpose of running it through a long simulation is to get the daily fluctuation and the long-term behaviour. It's not a full statistical way but it gives you an idea of the variation that you might see over that number of years."

Chuck: "We ran the optimization model twice. Once for an average year and once for a dry year. This gave two separate optimizations. But by inspection we could determine the most appropriate operating rules."

Tung: "We put these numbers into POP and ran the continuous simulation. The duration curve shows that the desired 75 KW of summer energy can be produced about 80% of the time. We used the optimization results in the POP simulation by setting the maximum and minimum reservoir levels to the values given by the optimization. The point of all this is that we required no trial and error. These results came from the first run."

Chuck: "This is the type of thing that should be in POP. We were never able to convince B.C. Hydro to incorporate this capability in the program, at least not as the initial development step. It would be reasonable to expect that if you give the program the economic data it should return the most reasonable starting point for your engineering judgment."

Dave: "I think if we can sum up in terms of the agenda, we have identified that the package has a strong point in that it has POP in it. However, as it is currently set up it has some serious limitations because it does not include an optimization routine."

John: "Yes and I think it should be oriented towards a stand-alone load, not connected to a transmission grid, which is what it's going to be used for in small hydro most of the time. It should have the diesel plant in it."

Dave: "Yes. It should reflect the reality of small hydro developments which throughout most of the Province are all stand-alone systems."

Roger: "On June 9th and 10th of this year there will be a forum at which B.C. Hydro will explain what they are going to allow people to send to the grid. There are about five people out there right now who are ready to go with a small hydro plant connected to the B.C. Hydro grid."

John: "I think another strong point is that GAP is a pretty good program. In some cases it would be good to have a tabular format as well as the graphs. The program could provide all sorts of summaries including the monthly flows."

Tung: "You mean it could read the whole period of record and then summarize them since it would have everything in memory at one time.

GAP will not do this right now."

Dave: "How about having a table generated from the output of each year of simulated record. You could print on a file somewhere the maximum, minimum and average flow for the year and for the months. This would be done as part of BCSIM."

Yaroslav: "Each time you run BCSIM it could print a little summary table on the screen when its finished showing the minimum, maximum and mean values for each year that was simulated. This is similar to the little summary table that appears when you are finished running POP."

Chuck: "The other thing is that there are different types of data involved and we may want summaries for all of them. GAP might be a better place to do these calculations. The way to do it would be to change GAP so that it does exactly what we want it to do. If we make the changes properly we will also have the capability to move backwards in time. At the present time you can only go forwards when you view the results with GAP.

I think the three strong points are the availability of the UBC Watershed model, POP, and GAP. That summarizes my perception. Through my experience I do not think that the precipitation part of the package is a strong point. I wouldn't trust it anywhere in the Province because I don't know whether it's working or not at that location.

If there was some way in which it could be filtered or differentiated so that certain areas are blocked out perhaps it might be more useful."

John: "I don't know. When I fiddled with it I seemed to have got reasonable answers."

Yaroslav: "It's an interesting approach and I think it's got promise. But there is a long way to go and a big effort involved."

Chuck: "Should we just take out the first program in the package, PRECIP, and throw it away?"

Dave: "Right. Then you could look up the precipitation in a climatological atlas of the world." (Laughter).

Chuck: "Is the issue about the appropriateness of the precipitation grid or the basic approach of having a model that's driven by precipitation as opposed to a regional analysis based strictly on streamflow data?"

Dave: "I come back to the idea that this package is a tool box. Some of these tools are immediately useful and some of them you may have to bend a little bit depending upon the particular problem that you have. In some applications you may go to the box of tools, and looking at the hydrology you may say that you can make a good estimate of precipitation on this basin because there is an AES station and some real data right there. So, you will take a crack at using BCSIM for this one. You may feel pretty confident especially if you get a good comparison between the simulated flows and the flows you get by making a comparison with some nearby watersheds.

For another problem you might have no idea of the precipitation and you wouldn't feel comfortable using BCSIM on this application. However, what you could do in the absence of other information, is to take this Water Survey of Canada data from the Cottonwood River, for example, and just correct it by the drainage area and push it through POP and see how much energy you get. That's another way of doing it. It could be another way of doing the same problem or different applications to different problems. It will all depend on where you are, how much information there is, how much time you have available, what the client wants and what he's willing to spend on this particular level of effort.

These programs are all tools that you might use at different times. I think what we're saying is that PRECIP is currently a tool that we'd all rather throw away and not bother even using. However, the BCSIM tool is useful in certain applications and the POP tool is useful in certain applications, especially if we have the ability to wheel in any particular Water Survey of Canada data.

We're not thinking of this any more as a set of procedures that you should use in order to arrive at an installed capacity of any given site. We are thinking a little more flexibly now about a way in which we can use all this stuff. For some jobs we might use part of the package and for others we might not use any of it."

Patrick: "I think we're really in need of an improvement to the precipitation grid."

Chuck: "Danard has looked into what would be involved in determining the elevations at which the precipitation values apply. He could generate a second grid which shows the elevations at which each of the precipitation values apply. It would not be very costly to do that but I would be concerned about whether we would be any better off than we are now because we would still have to come back to this room and do the validation again. The fact that it can be done doesn't mean that it will produce the results that we want.

To calculate the elevation which is relevant to each one of those grid points is not a minor job but it's not a major task either.

The atmospheric model would be run again to compute the elevation of each grid point. The topographic data is of course already available.

I don't know that there would be a lot of recalibration because I think we know that Tony Pipes understood this problem when he did the calibration initially. But we would have to go through the validation again. The reports which Danard wrote to the Province discuss how he did the work. Tony read these reports very carefully and did a thorough job of calibration with this in mind.

I am simply saying that it may be only ten days to recompute the grid but there might be another 30 man-days involved in determining whether or not we've done any better in the way in which the package can be used."

Yaroslav: "And that's still using the 1941 - 1970 data. Now there is a lot more information.

At the same time we should go on to the final step which would be to make a grid that has precipitation values that represent the situation at ground elevation. If you had a finer mesh than ten minutes we would have the most reliable isohyetal map that's ever been created for the Province of B.C."

Roger: "In order to test the model we would need to have a statistically significant number of gauged watersheds, perhaps 200 or 300, before we would really know whether we've got much improvement."

Chuck: "But couldn't you say that if the precipitation grid was accurate over the area of one grid point, which is about 250 sq km, that it would represent the average conditions over an area of that size? Now if you have a micro climate within that 250 sq km you would have to adjust the precipitation value in some other way."

Roger: "I don't think we know what's going on within a 250 sq km area at this point in time. We don't have enough information. I don't think there is anybody in Washington or Oregon, and possibly only a few people in Colorado that can tell you what's going on at that level of detail.

Whatever we do it has to be tested. Here we had five people. Some were 50% or 60% low, Patrick was out by a factor of 3. That doesn't give you a lot of confidence. We really have to work the entire front end of this package."

Chuck: "You could put the latest AES data right into the grid. You could also use the Water Survey of Canada data to calculate precipitation."

John: "You need to be able to take the Water Survey data for the gauged basin and make some correction for elevation at the hydro site."

Chuck: "This is where we have a fundamental difference of opinion about the regional hydrology approach. I see two things which affect runoff. One is the weather and the other is the watershed. When you look at a Water Survey of Canada gauging record it has everything integrated together. If you have a watershed model you can disaggregate and back out what the precipitation must be. This allows you to get it out separately from the routing characteristics of the watershed. If that could be done then each one of these Water Survey of Canada gauging stations would be some kind of an integrating rain gauge covering all the elevations. Thus, if you have a Water Survey of Canada gauging record but no AES records you could take a shot a guessing at the regional precipitation. That would probably be even better than the existing precipitation grid we are using."

Roger: "Tony Pipes did some of that type of analysis. He found on the coastal streams that there was more runoff than there was precipitation from the nearby AES station. He had hundreds of watersheds he had analyzed that way and written the results on a map. It was fascinating but I think it is a major research project."

Chuck: "Well, wait a minute now. We don't want to get going around in circles. What he showed was that the Water Survey of Canada stations are measuring a different climate from the AES stations. When you get more precipitation calculated from the runoff record than you get from the rain gauge, I would make the conclusion that the rain gauge is not representative of the watershed.

It seems silly to use a rain gauge to estimate precipitation on a watershed when it represents what is happening at only one single point. We are not interested in a single point measurement, we are interested in calculating the runoff from a watershed. So why not use the watershed to estimate the precipitation that will be used in the model?"

Neill: "I think we said right at the outset that precipitation is more transferable than streamflow."

Yaroslav: "If we use a model to back away from streamflows to get precipitation we raise the question of reliability of the model. This is an abstract value that never really happened. If we had measured precipitation over the entire basin that would be a real thing. But when we back up and estimate the precipitation from the streamflow we are getting much different numbers."

Chuck: "Yes, but tell me more about how you go from one watershed to another across a range of mountains in a regional hydrology study? I don't have that kind of faith."

Yaroslav: "You would have two things to worry about. One is backing up the precipitation and the other is transferring that precipitation to the other watershed and estimating the flows with the model. Personally I would rather deal with things that I have some faith in. I'll look at this watershed and see what the flows are. I'll look at the characteristics of that watershed, the elevation, the hypsometric curve, the number of lakes, the area of snow covered glaciers, aspect perhaps, the isohyetal trend across the area, and use that information in a kind of subjective modelling. From that I would come up with an idea of how I should treat those flows in that watershed to come up with estimates of flows in this watershed. I still think that's the best thing going."

Dave: "I think we are getting off base here a bit. We are talking about how we would each individually apply the tools in different circumstances."

Harry: "We were talking about limitations of the package and the first big one was the PRECIP program."

Chuck: "The whole approach to the runoff modelling is in question. I haven't heard anyone support the idea. From what I heard everyone wants to use streamflow data directly."

Harry: "I did not hear that. I heard that it would be nice to have more streamflow data so that a viable option in the use of this package is to simply go straight into analysis with the POP programs.

I also heard people say that they will look at the precipitation but they will also look at the flows. And if they think that what they're looking at approximates the way the watershed behaves, then they will use it. But they don't want to be locked in one way or the other and they don't want it to be a cook book recipe that always must start with PRECIP."

Dave: "I would want to use these programs in any particular way depending upon the particular application. If I felt that I had a good AES station that was reasonably representative of the catchment and if I was able to do a calibration on a catchment which I considered to have similar characteristics then I would apply BCSIM with a certain degree of confidence. But I certainly would not apply BCSIM using AES data that was not representative of the catchment."

Harry: "And that brings me to the second idea that I heard. This is really a package for experts. That's a limitation only in the sense that of the work does not provide a tool for the average rancher. I don't personally view that as a limitation in the larger sense."

Roger: "Well I think if we go back one level from the calibration and simplify some of the constants it may be useful to a rancher in some circumstances. More importantly though it could be a very useful tool to people who have the time and the knowledge to push the level of hydrology more than one step in some applications. I think this could be a quantum leap in a practical sense. It is going to be risky - there will be mistakes made."

Adrian: "The Department already has this big, thick grey-covered handbook on small hydro and surely that is the avenue to get at the small rancher."

Roger: "That's right and the next step is when they come back to say "I've got this figured out but can you do a simulation?" and I can say, or a consultant can say, "Sure, I can do a run and spend a half-day on this with the IMP Package", except that I have to be aware that I could be out 20% or 30% or by a factor of 3! The next step is to go out in the field and put a weir in and get some actual measurements."

Harry: "Well, another limitation is the missing data problem. There are several aspects to the missing data problem. There is the literal aspect and then there is the fact that there are gaps in the AES and streamflow records."

Roger: "My first step, quick and dirty, would be to produce a list which shows what is missing."

Dave: "If you are operating on a water year basis it might be acceptable to skip a year if there are a lot of days, or a month missing."

Chuck: "GAP would need to be intelligent enough to know that there is a year missing otherwise all the labels would be wrong."

Harry: "Now, let's talk some more about limitations of the IMP package. Never mind the little annoyances in the programming."

John: "Well the manipulations that are required to deal with the grid values before they are input into the package is a problem. You should be forced to do that on the screen rather than mentally or on a piece of paper. It should be built into the program."

Roger: "I think you could re-number the programs and put the PRECIP package at the end. This should reduce the temptation to use it except as a last resort."

John: "We have to call that a precipitation index or something because it isn't really precipitation."

Harry: "The big problem with all of that is that it's not so much where the things sits on the menu screen, it's in how the documentation is billed. You could re-do the manual without really changing the concept of the software.

I think we all agree that the package is releasable with lots of caveats even in the form that it is in now. In particular, we have to make clear, somehow, that there are perils in the PRECIP program. The manual should make that clear.

We haven't talked yet about the training aspects.

Yaroslav: "We are all in a privileged position having had access to this workshop. We have learned where the loop-holes are and we really know how to do this thing now. It would be difficult for someone just getting this in the mail.
The way it is now, if we were going to release it this afternoon I would recommend against that."

Roger: "If somebody wants a package I would spend half a day with them. It's not a big deal anyway because there would probably be only 2 or 3 people come in during a year. Now, I don't know that I'm a qualified user although I have a much better idea now than when I started. There's been a lot discussed here."

Dave: "In terms of your potential audience in B.C. you've probably got half of them right here in this room."

Roger: "Can we reach consensus that we are going to operate this on a calendar year?"

Dave: "I would actually prefer a water year basis but I can see reasons why a calendar year would be preferable."

Chuck: "Another improvement would be to have BCSIM write the name of the AES station that was used as input for this simulation. The way it stands now by touching a wrong button you could end up with a simulation based on the wrong AES station without knowing it."

John: "And the way it stands now it doesn't show the long term mean annual precipitation that was used for the hydro site.

There are also places in the program where it asks for English and Metric units and the answers are not always consistent in the way they are stated. The yes-no question that comes up with the file listings is annoying as well. That should be eliminated. "

Harry: "Well there was some question about using Metric alone. We could do that."

Adrian: "This number of sub-basins equal to two meaning one should be changed."

John: "In POP1 where it asks for the number of reservoirs the answers seem to be arbitrarily inconsistent.

If you want one reservoir you punch two. If you want no reservoirs you punch one."

Yaroslav: "We also had some problems with the colours that are used in the display from FFA. On some computers we couldn't see anything."

(Note: The tape ended here. There was some additional discussion for a few minutes, but no new issues were raised.)

INTEGRATED METHOD FOR POWER ANALYSIS (IMP)

SECTION V - BIBLIOGRAPHY

Acres International Limited, "Hydrologic Design Methodologies for Small-Scale Hydro at Ungauged Sites - Phase II - Feasibility Level Study for Atlantic Provinces," for Environment Canada, Mines and Resources, Canada, Study Documentation Report, Summary Report, and Applications Manual, April 1985.

Atmospheric Environment Service, "Temperature and Precipitation, 1941-1970, British Columbia," 94 pp.

Blank, Robert G., "The Allocation of Resources by Linear Programming," Scientific American, June 1981, Vol. 244, No. 6, p. 126.

Charles Howard & Associates Ltd., "Flood Frequency and Hydrograph Analysis for Ungauged Watersheds," Bureau of Indian and Northern Affairs, Northern Affairs Program, March 1978.

Charles Howard & Associates Ltd., "POP - User's Manual, Project Oriented Program for Simulation of Hydroelectric Development Projects," for B.C. Hydro, Hydroelectric Generation Project Division, December 1982.

Crippen Consultants, "MICRO HYDRO", Volume I - "A Survey of Potential Micro Hydro Developments for Use by Remote Communities in British Columbia;" Volume II - "Guidance Manual of Procedures for Assessment of Micro Hydro Potential;" Volume III - "Site Investigations - A Survey of Potential Micro Hydro Developments for Use by Remote Communities in British Columbia," for the Ministry of Energy, Mines and Resources, Conservation and Renewable Energy Policy Division, October 1980.

Danard, M.B., "Mean Annual Precipitation (1941 - 1970) Over British Columbia," for Water Investigations Branch, Water Resources Service, Province of British Columbia, Report No. 24, 1980.

Danard, M.B., "Maximun 24H Rainfall in Northern Interior British Columbia," for Water Investigations Branch of the Ministry of Environment, Province of British Columbia, Report No. 23, 1979.

Danard, M.B., "A Physical Model for the Variation of Precipitation over the Toquart Watershed," Report No. 14, prepared for Water Investigation Branch, 1974, 27 pp.

Danard, M.B., "A Model for the Variation of Precipitation over the Greater Vancouver Water District Catchment Basins," Report No. 15, prepared for Water Investigations Branch, 1975, 22 pp.

Danard, M.B., "24 hr Rainfall Amounts for Various Return Periods over Southwestern British Columbia," Report No.17, prepared for Water Investigations Branch, 1975, 37 pp.

Danard, M.B., "24 hr Rainfall Amounts for Various Return Periods over South-central and South-eastern British Columbia," Report No. 21, prepared for Water Investigations Branch, 1978, 28 pp.

Danard, M.B., "Maximum 24 hr Rainfall in Northern Interior British Columbia," Report No. 23, prepared for Water Investigations Branch, 1979, 91 pp.

Eagleson, Peter S., "The Stochastic Kinematic Wave," Proceedings of the United States - Japan Bi-Lateral Seminar in Hydrology, Honolulu, January 1971, pp 202-225.

Environment Canada, "Analysis and Use of Urban Rainfall Data in Canada," Environmental Protection Service, Report EPS 3-WP-79-4, 1979, 35pp.

Flatt, Paul, and Howard, Charles D.D., "Preliminary Screening Procedure fpr Economic Storage-Treatment Trade-offs in Stormwater Control," International Symposium on Urban Stormwater Management, Lexington, Kentucky, July, 1978.

Hage, K.D., "On Summer Cyclogenesis in the Lee of the Rocky Mountains," Bull. Amer. Meteor. Soc., 42, 1961, pp. 20-33.

Harley, Brendan M., "Sensitivities of Hydrological Engineering Design Models to Meteorological Inputs," 2nd Conf. on Hydrometeorology, Joint AMS and CMOS Meeting, Oct. 25-27, 1977, Toronto, Ontario, Canada.

Howard, Charles D.D., "A Study of Hydrologic Phenomena in the Yukon Territories," Report by UNIES Limited, for Comptroller of Water Rights, Yukon Territory, Department of Indian Affairs and Northern Development, Whitehorse, March 1975.

Howard, Charles D.D., and Smith, D.DI., "Floods on Ungauged Watersheds," Canadian Hydrology Symposium, Edmonton, August 29-31, 1977.

Leith, R.M., "Streamflow Regionalization in British Columbia, No. 1, Regression of Mean Annual Floods on Physiographic Parameters," Report Series No. 40, for Environment Canada, Inland Waters Directorate, Pacific Region, Water Resources Branch, 1975.

Leith, R.M., "Streamflow Regionalization in British Columbia, No. 2, Regression of Mean Annual Flows on Physiographic Parameters," Report Series No. 46, for Environment Canada, Inland Waters Directorate, Pacific Region, Water Resources Branch, 1976.

Leith, R.M. "Streamflow Regionalization in British Columbia, No. 3, Statistics of Mean Annual Flow," Report Series No. 50, for Environment Canada, Inland Waters Directorate, Pacific Region, Water Resources Branch, 1977.

Leith, R.M., "Streamflow Regionalization in British Columbia, No. 4, Regression of Low Flows on Physiographic Parameters," Report Series No. 57, Environment Canada, Inland Waters Directorate, Pacific Region, Water Resources Branch, 1978.

Quick, Michael, C., and Pipes, Anthony, "A Combined Snowmelt and Rainfall Runoff Model," Canadian Journal of Civil Engineering, Vol. 3, No. 3, 1976, pp. 449-460.

Quick, Michael, C., and Pipes, Anthony, "Formulation of the UBC Waterhsed Model," Snowmelt Model Used in Operational Forecasting of Snowmelt Runoff, WMO Intercomparison Project, Geneva, March, 1983.

Sigma Engineering Ltd., "Small Hydro Power Resource in the Provincial System - Technology and Resource Assessment," for Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Conservation and Technology Division, February 1984.

Sigma Engineering Ltd., "Small Hydro Power Resource in the Provinicial System - Economic and Financial Assessment," for Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Conservation and Technology Division, February 1984.

Sigma Engineering Ltd., "Feasibility of Supplying Hydro Power to Moses Inlet, B.C. Forestry Camp Under Contract," for Lancaster Resource Corportation, March 1984.

T. Ingledow & Associates Limited, "British Columbia Hydrometric Network Study," for Government of Canada, Department of Energy, Mines and Resources, Volumes I and II of Interim Report, March 1969, Volumes I and II of Report, April 1969.

Titus, R.L., "Upper Air Climate of Canada - Charts of Monthly Geopotential, Temperature and Humidity, 1951-1960," Toronto, Meteor. Branch, Dept. of Transport, 1967, 103 pp.

Wooding, R.A., "A Hydraulic Model for the Catchment-Stream Problem. I Kinematic Wave Theory," Journ.Hydrol., Vol.3, now 3/4, pp. 254-267, 1965.